Optimization of Service Parts Planning for InFocus

by
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Abstract

A common problem faced by many industry companies, including InFocus, is that they are holding excess inventories and incurring unnecessary inventory holding costs yet are not able to achieve their expected customer service levels. This problem is critical to be addressed for companies who are striving to lower their supply chain costs and improve their management efficiencies. One solution to this problem is to use better forecasting methods and employ the appropriate inventory management policies.

The objective of this project is to review the software package, Servigistics software tool, used by InFocus, to evaluate if it is suitable for InFocus' operations and to identify any improper practices when using Servigistics.

The first step to address the problem is to review and evaluate Servigistics software package qualitatively. We found that Servigistics is a sound software tool with appropriate inventory and forecasting formulas. But the information fed into Servigistics is not accurate and up-to-date; this results in inaccurate results output by the Servigistics software.

The second step is to evaluate Servigistics' output and InFocus' inventory management policy quantitatively. We found that InFocus has not been managing their inventory scientifically and for certain service parts, they procure excessive amounts in one shot. Approximately USD 3.8 million can be saved if InFocus manages its inventory scientifically using the current forecasting method. The major improvement comes from more discipline in their inventory management.

Thesis Supervisor: Stephen C. Graves, Professor of Management Science

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Chapter 1 InFocus background [1]

Founded in 1986, InFocus has been the projection industry pioneer and one of the worldwide leaders in industrial design and research and development of projectors. It has introduced some ground-breaking products such as flat-panel overhead display, the first handheld sub-two-pound data/video projector and the only home theatre projector with premium features that include HDTV compatibility and digital connectivity. InFocus Corporation's global headquarters are located in Wilsonville, Oregon.

Being driven by the reduction of projectors' prices, InFocus had to react and restructure its business in 2005 in order to lower the cost of production and save the company from a financial crisis. On a reported basis under generally accepted accounting principles, gross margins were negative 0.4 percent, the net loss was $38.3 million and the net loss per share was $0.97 for the third quarter of 2005. In mid-September 2005, the company announced a comprehensive restructuring plan as part of an overall initiative to simplify the business with the goal of returning the company to profitability in the first half of 2006. At that time, the company indicated its goals were to reduce its delivery cost, increase its supply chain efficiency to reduce product costs, and reduce other operating costs with a goal of returning gross margins to between 16 and 18 percent and reduce operating expenses by 20 to 25 percent from reported second quarter 2005 levels. Since the announcement, the management team has initiated a number of actions to simplify the business and reduce their operational costs. That is where three of us, the MIT interns came into the picture to help InFocus to improve their supply chain efficiency.

Chapter 2 Problem statement

As part of InFocus' goal to improve its supply chain efficiency, I am assigned to work in the area of reverse logistics, studying their service parts planning, forecasting and inventory management processes. InFocus was and is still faced with the problems of low demand satisfaction and bad inventory management. Low demand satisfaction refers to the cases when InFocus needs certain service parts for repair jobs, the desired service parts are not available in the warehouse and this situation results in delaying the completion of the repair jobs and failing to keep the promised projector turn around time to customers. Customers may eventually turn away from InFocus and buy other brands that can provide better services. Bad inventory management eventually led to the situation of InFocus holding excess inventories for service parts that are not needed and short of inventories that are in need. According to the inventory report generated in early June, 2006, InFocus is holding USD 13 million excess inventory and at the same time, has inventory shortages equivalent to USD 10 million as summarized in table below. Their current service parts inventory level is around USD 21 million. The measure that InFocus uses to describe the inventory is that, if the inventory level of a particular service part is above the sum of its "Re-order Point" and its "Economic Order Quantity", we declare that service part as having "excess inventory"; if the inventory is below the safety stock level, we declare that service part is in "critical shortage" state. Hence, a quick calculation will tell us that the desired inventory level can be roughly approximated to be around USD (21-13+10) which is equal to USD18 million.
However, the accuracy of this number is in doubt. As we will report later, some of the information used by Servigistics to calculate the safety stock level and the re-order point is not very accurate. For example, the standard deviations of some service parts' procurement lead time are much bigger than the actual values, which results in the re-order point and safety stock levels being too large, as calculated by Servigistics. But the actual service parts inventory worth of USD 21 million is an accurate number, confirmed by other databases other than the record kept by Servigistics. We will demonstrate that InFocus can at least save USD 3.8 million worth of service parts based on 17 case studies using the most expensive service parts, engines. Currently, InFocus uses a software tool named Servigistics for service parts planning, forecasting and inventory management. Hence, I am assigned to study the "Servigistics" software and try to

identify the reasons which may account for the undesired service parts inventory levels and low demand satisfactions.

Table 2-1 Excess and shortage inventory snapshot for InFocus

Location	USRC	USFG	EURC	EUL	DXRC	APL	Total
Excess	$227,453	$2,743,573	$23,530	$9,566,112	$143,606	$335,410	$13,039,683
Shortage	$187,454	$6,878,309	$36,133	$2,004,845	$46,882	$911,673	$10,065,297

The first row lists InFocus' worldwide warehouses. There are two warehouses in US, USRC and USFG. USFG serves as the worldwide central warehouse. The last-time-buy of large amount of service parts are all stored in USFG and being distributed to other warehouses in the world. Three warehouses are present in Europe right now and they are EURC, EUL and DXRC in short. APL serves as the central warehouse for Asia-Pacific region. The second row, "Excess" represents the amount of excess inventories that are held at each warehouse; the third row, "Shortage" indicates the needed inventories at each warehouse. Their units are both dollars.

Chapter 3 Motivations

In consideration of what has been described and presented in the section of "Problem Statement", we believe that there are four important motivations that drive InFocus to pay close and careful attention to their service parts planning, forecasting and inventory management. They are summarized below as:

- Improve customer satisfaction to maintain or even expand their customer database;
- Provide more accurate forecasting so that less inventories are required to satisfy the specified customer service level;
- Improve the inventory management process to achieve the desired inventory level under the specified customer service level ;
- Reduce the inventory holding cost of service parts by achieving the above three motivations to reduce the operation cost for reverse logistics management and help to return the company to profitable;

Firstly, in order to give a quick overview of what its current customer satisfaction is, a table is presented below, summarizing the actions required for InFocus to take output by Servigistics software. The column under "Critical Shortages" tells us how many service parts in each location are below their respective safety stock levels, including the cases of out of stock. By dividing the number of service parts in "Critical Shortages" state by the total number of service part in the system data base, i.e.

$\frac{1757}{642+40+1010+1757+4426} \times 100\% = \frac{1757}{7875} \times 100\% \approx 22.3\%$, we obtain that 22% of the service parts are in "critical shortage" state. So it tells us that it is highly possible that 22% of the total service parts are not able to meet the expected customer service level as they are not holding sufficient inventories to cover the variation in demand.

Table 3-1 Action required summary for InFocus owned regional warehouses

Action needed for each location					
Name	**Procurement**	**Repair**	**Replenishment**	**Critical Shortages**	**Excess**
USFG	277	24	32	527	1660
APL	149	0	70	205	821
ALC	3	0	27	25	7
EUL	209	16	142	322	1194
DXRC	0	0	370	313	232
ELC	4	0	22	66	27
EURC	0	0	256	194	106
USRC	0	0	91	105	379
Total	642	40	1010	1757	4426

Secondly, apart from the customer satisfaction problem, InFocus has never done any analysis to quantify their forecasting accuracies. Currently they are using 6-month weighted average method provided by Servigistics tool. But the reason behind choosing this method compared to other available ones is not clear and the decision is made without verification or comparison.

Thirdly, as reported in previous section, InFocus is holding USD 13 million of excess inventories and is short of USD 10 million inventories. Even though these two numbers may not be completely accurate, we have observed that there are opportunities fro improvement in how InFocus manages its inventories. For instance, InFocus has been buying some service parts in huge amounts, much in excess of its economic order quantities. We will show that indeed there are many opportunities to improve the management of inventory by following more disciplined inventory policies.

Chapter 4 Literature review

Overview: As the main objective of this thesis project is to examine InFocus's current service parts planning system and the associated practices to see if there is any room for improvement or optimization, the literature search is focused on three areas: the available forecasting methodologies for service parts planning, forecasting accuracy measures for service parts planning and the inventory management models.

4.1 Forecasting methods for service parts planning

When efforts were spent on searching for forecasting methods used for service parts planning, quite a number of papers about forecasting of "intermittent" or "slow-moving" parts, e.g. "Accurate Intermittent Demand Forecasting for Inventory Planning: New Technologies and Dramatic Results" by Charles N. Smart, President, Smart Software, Inc [2], were found; and in many situations, service parts are referred to as "slow-moving parts" having intermittent demands. But this is not the case for InFocus. This is because, when we look at the selected service parts demand, i.e. the demand records of the 17 most expensive service parts, the 17 engines, in monthly buckets, they are well filled up in each month and there is almost no occurrence of very low demands in any particular month in the middle of the projector service life cycle. The demand picks up quickly in a few months' time after the projector is launched into the market. And the demand only drops significantly when it is near the end of service life as there are very few active or working projectors in the field as InFocus offers three years service operations after the end of projectors' sales. This observation is made based on the selected 17 service parts and it may not be the case for all the parts.

As one of the reputable and experienced service parts planning software providers, Servigistics Inc, provides some useful forecasting methods for service parts planning. This information is obtained from their training manual provided to InFocus as one of its clients. The available forecasting methods catered for service parts planning are briefly reviewed below:

a) Moving Average forecasting [3]: it takes the average of the specified number of past months' records and use it as the forecast of next month. Whenever new information is available, the oldest data will be dropped off and the average will be updated. It is best used when there is no trend in demand history. The window of data used in calculating the forecast moves forward as time progresses.

b) Weighted Average forecasting [3]: it calculates the weighted sum of the past demand and uses it as the forecast of next month's demand. It typically assigns more importance, higher weight, to the most recent month and assigns lower weights to older demand data depending on how many slices of past records are used. It responds to trends more quickly than a moving average forecast, but it still gives a flat-line forecast with no trend identified.

c) Linear Regression method [3]: a linear formula characterizing the past demand is obtained and a projection of next month's demand will be obtained using the linear formula. It produces the most accurate forecasts when there is a definite trend in the demand history. This trend in demand history is carried out through the forecast period.

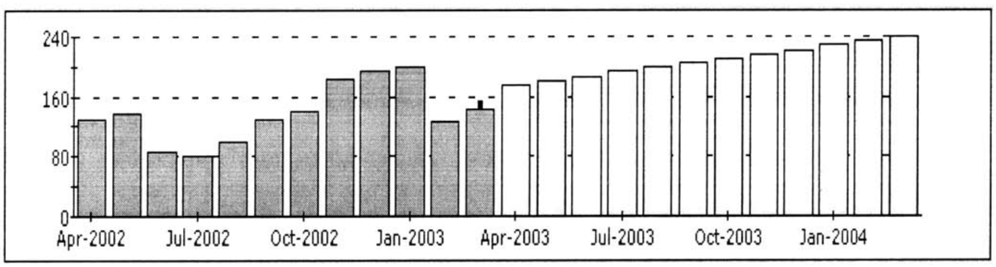

Figure 4-1 Illustration of linear regression method

The figure presented above displays how the demand and forecast look for a linear regression forecast. The columns in brown represent the past demand records and those in yellow represent the forecasted demand for next year. As described, the forecasted demand actually has a linear trend using the first order formula obtained using the past records.

d) Single Exponential Smoothing (SES) method [3]: it uses a weighted moving average forecasting, but the forecast is updated from month to month by smoothing the old average and the new demand observation together rather than simply replacing the old average with the new one. It weights past data with weights that decrease exponentially with time; that is, the more recent the demand observation, the greater the weighting it has. Effectively, SES is a weighted moving average system that is best for data exhibiting a flat trend. Hence, it will give a flat-line forecast, but one which shifts less erratically from month to month. The formula used for SES is: $S_t = \alpha y_t + (1-\alpha)S_{t-1}$. S_t represents the "smoothed estimate" for next month; S_{t-1} represents the "smoothed estimate" for the previous month; α is the smoothing constant and it is a value between 0 and 1; y_t represents previous month's demand.

e) Double Exponential Smoothing (DES) method [3]: it calculates a trend in the demand history similarly to Linear Regression method. However, the trend is updated from month to month by smoothing the old trend and the new trend together in the same way as the moving average method. It applies Single Exponential Smoothing twice. It is useful where the historic data series is not stationary.

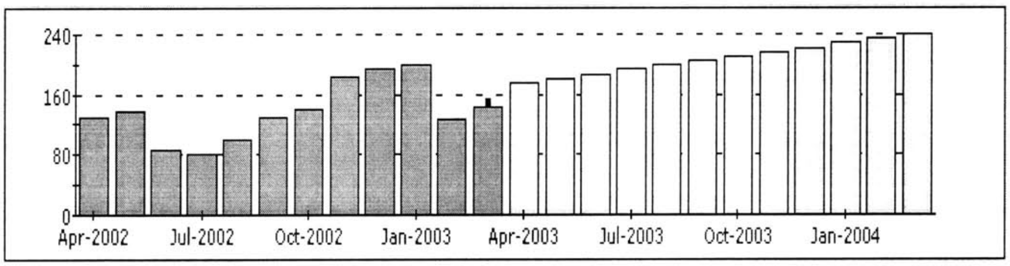

Figure 4-2 Illustration of Double Exponential Smoothing

The figure presented above displays how the demand and forecast look for double exponential smoothing. Again, the columns in brown represent what the past demand looks like and those yellow ones represent the forecasted demand for the next year.

f) Winter's Multiplicative method [3]: it functions the same as Double Exponential Smoothing, but with another factor, seasonal variations. Each forecast slice is assigned a seasonal index to account for annual variations in the demand. This index is updated monthly using smoothing. It is able to produce a very accurate forecast when both trend and seasonality are involved in a part's history.

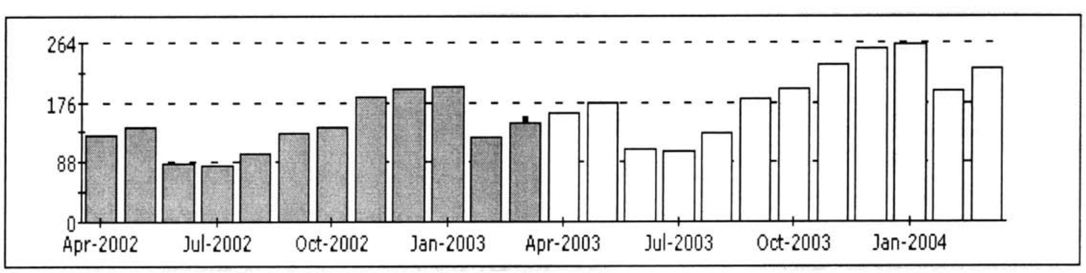

Figure 4-3 Illustration of Winter's Multiplicative method

The figure presented above displays how the demand and forecast look for Winter's method. The columns in brown represent the past demand data and those in yellow represent the forecasts for the next year.

g) Croston's Method [3]: it is designed to predict usage when the historical demand is intermittent or "spotty". Croston's method calculates the estimated interval between demands and the estimated quantity of that demand.

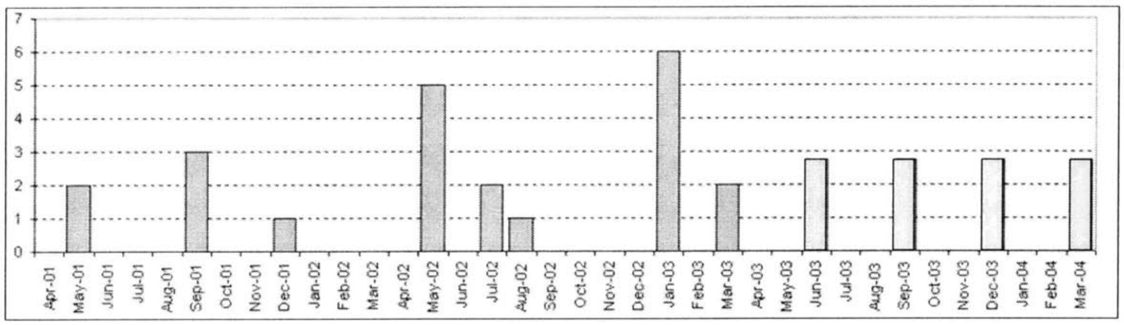

Figure 4-4 Illustration of Croston's Method

4.2 Forecasting accuracy measures

There are several commonly used forecasting accuracy measures. In "Error measures for generalizing about forecasting methods: empirical comparisions" by J. Scott Armstrong and Fred Collopy [4], measures used for making comparisons of errors across time series are evaluated. The few commonly used ones are reviewed below:

4.2.1 Mean Squared Error (MSE) [5]: it is defined as the expected value of the squared difference between the forecasted value, F, and the actual quantity, A. It can be represented as $E[(F-A)^2]$. Its square root, the Root Mean Squared Error (RMSE), represented by $\sqrt{E[(F-A)^2]}$, is another important measure of forecasting accuracy. For the purpose of easier communicating your results, RMSE is better than MSE as it is in the same units as the demand data, rather than in squared units.

4.2.2 Mean Absolute Error (MAE) [5]: it is the average of the absolute value of the difference between forecast and actual quantity represented by $\frac{1}{N}\sum_{n=1}^{N}|F_n - A_n|$. MAE is also measured in the same units as the original data and it is sometimes preferred over MSE or RMSE because it is easier to understand and less complicated mathematically. Also, it is often referred to as Mean Absolute Deviation or MAD for short.

4.2.3 Mean Absolute Percentage Error (MAPE) [5]: MAPE can be defined as an average of percentage errors over a number of products and it can be represented by the equation $\frac{1}{N}\sum_{n=1}^{N}\frac{|F_n - A_n|}{A_n}\times 100\%$. The forecast error can be larger than the forecast, F, or actual quantity, D, but not both. An error above 100% implies a very inaccurate forecast. MAPE is very useful for reporting purpose as it is in percentage terms rather than actual units; even for the case that it is unknown how big or small an absolute error could be in actual units, MAPE provides the insight of the relative size of the forecast error compared to the actual quantity.

4.2.4 Mean Error (ME) and Mean Percentage Error (MPE): they are calculated in the same way as MAE and MAPE without taking the absolute value of difference between the forecasted and actual quantity [5]. They are used sometimes as signed measures of error to determine if the forecast is biased by observing if there is obvious trend of disproportionately positive or negative errors. If any bias is observed, adjustment to the forecasting method should be made to provide unbiased forecasts.

4.3 Inventory management models [6]

The book, "Designing & Managing the Supply Chain" by David Simchi-Levi, Philip Kaminsky and Edith Simchi-Levi, is used as the main source for inventory management models. There are several inventory models available currently.

4.3.1 The classic "Economic Lot Size Model": it is introduced by Ford W. Harris in 1915 and is the simplest model which illustrates the trade-offs between the ordering and inventory holding costs. It considers the situation of a warehouse facing constant demand for a single item. The warehouse orders from the supplier and it is assumed that the supplier has unlimited ability to meet order requirements. There are several assumptions for this model:

- ✓ Demand is at constant rate of D items per day;
- ✓ Order quantities are fixed at Q items per day and each time the warehouses places an order, it orders for Q items;
- ✓ A fixed cost, K, is incurred every time the warehouse places an order;
- ✓ An inventory holding cost, h, is incurred per unit held in inventory per day;

- ✓ The lead time between placing and receiving an order is zero;
- ✓ Initial inventory is zero;
- ✓ The planning horizon is infinite;

Its goal is to find the optimal order policy that minimizes annual purchasing and carrying cost while meeting all demand. Apparently, this model illustrates the extremely simplified case where demand is known and constant; it takes zero amount of time to receive an order once it is placed. These assumptions are unrealistic. The contribution of this model is to obtain the "Economic Order Quantity" (EOQ) and it is found that the order quantity minimizing the cost is $Q = \sqrt{\frac{2KD}{h}}$;

4.3.2 Continuous review policy: it is another one in which inventory is monitored and reviewed every day in order to make the decision of whether to place an order and for how much. Some additional assumptions are made on top of the classic model:

- ✓ Daily demand is random and follows a normal distribution and the forecast of daily demand follows the bell-shaped curve. Average and standard deviation are used to describe the normal demand;
- ✓ Every time an order is placed, a fixed cost, K, plus an amount proportional to the quantity order is incurred;
- ✓ Inventory level is reviewed at the end of every day and if an order is placed, it will arrive after some lead time and the lead time is characterized by average and standard deviation also;
- ✓ In case of distributor stocking out, the order is lost;
- ✓ The distributor specifies an expected service level. The service level specifies the probability of not stocking out during the replenishment lead time period or in another word, the probability of meeting the demands using stocked inventory during the lead time period;

The following information is needed in order to characterize the inventory policy:

- ✓ AVG: average daily demand faced by the distributor;
- ✓ STD: standard deviation of daily demand faced by the distributor;
- ✓ L: replenishment lead time from the supplier to the distributor in days;
- ✓ h: inventory holding cost per unit per day at the distributor;

✓ α : service level, the probability of not stocking out during the lead time;

The inventory position used in this model refers to the actual stock available at the warehouse plus items ordered by the distributor that have not yet arrived.

The policy is also referred to as an (s, S) policy where s and S refer to reorder point and order-up-to level respectively. Whenever the inventory position drops below s, the distributor should order the amount that will raise its inventory level position to level S.

The reorder level, s, has two components. The first component covers the expected demand during lead time and it is represented as $L \times AVG$; the second component refers to safety stock which is the amount used to cover the demand uncertainty during the lead time and it is calculated as $z \times STD \times \sqrt{L}$. z is a constant named safety factor and it is associated with the service level. For normal distributed demand, there is a look-up table available for proper z value selection for the specified service level.

Thus, the reorder level s is represented as $L \times AVG + z \times STD \times \sqrt{L}$;

EOQ is calculated as $Q = \sqrt{\frac{2K \times AVG}{h}}$ in this model;

Order-up-to level S = Q + s;

The expected level of inventory before receiving the order is the safety stock: $z \times STD \times \sqrt{L}$;

The expected level of inventory immediately after receiving the order is: $Q + z \times STD \times \sqrt{L}$;

Thus, the average inventory level is the average of the above two values, which is equal to: $Q/2 + z \times STD \times \sqrt{L}$;

However, in many cases, the assumption that delivery lead time from manufacturer to warehouses is fixed and known in advance does not always hold. In many real life situations, the lead time to warehouses is assumed to be normally distributed with the expected lead time denoted by AVGL and standard deviation denoted by STDL. In this case, the reorder point s, is calculated as follows:

$s = AVG \times AVGL + z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$;

$AVG \times AVGL$ represents the average demand during lead time, while $\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$ is the standard deviation of demand during lead time. Thus, the safety stock that has to be kept is equal to:

$z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}$. Similarly, the order-up-to level, S, is the sum of the reorder point and Q, i.e.:

$$S = Q + AVG \times AVGL + z\sqrt{AVGL \times STD^2 + AVG^2 \times STDL^2}.$$

4.3.3 Periodic review policy: inventory level is reviewed periodically after certain regular interval and an order is made for the appropriate amount after each review. As inventory is reviewed periodically, the fixed cost of placing an order is a sunk cost and is usually ignored. In view of this, the inventory policy is characterized by the base-stock level only. That is, the warehouse will specify the target inventory level, the base-stock level and at each review period, the inventory position will be reviewed and the amount that will raise the inventory level back to the base-stock level will be ordered. An additional parameter shall be determined for this model on top of that for continuous review policy:

- ✓ r: the length of the review period, i.e., inventory position will be reviewed after each r period;

Similar to the reorder point s in continuous review policy, the base-stock level has two components also:

- ✓ Expected demand during the interval of r + L days, represented as: $(r + L) \times AVG$;
- ✓ Safety stock: $z \times STD \times \sqrt{r + L}$ where z is the safety factor as described before;

The expected level of inventory after receiving an order is equal to:

$r \times AVG + z \times STD \times \sqrt{r + L}$;

The expected level of inventory before an order arrives is just the safety stock, $z \times STD \times \sqrt{r + L}$;

Hence, the average inventory level is the average of these two values, which is equal to:

$\frac{r \times AVG}{2} + z \times STD \times \sqrt{r + L}$;

Chapter 5 Approach

In consideration of the problem given by InFocus, we decided to approach the problem in two major steps. There are sub-steps within each major step.

5.1 First major step:, study and evaluate Servigistics software: we decided to study how Servigistics does the planning, forecasting and inventory management of service parts for InFocus. To be more specific, we expected to find out:

- ✓ What information is fed into Servigistics and if the information is accurate and up-to-date;
- ✓ What kind of forecasting method Servigistics uses and how it makes use of the information fed into Servigistics;
- ✓ What kind of inventory management model Servigistics uses and how it makes use of the information fed into Servigistics;
- ✓ Whether or not the appropriate operation practices are carried out following the instructions output by Servigistics;

The first step will help us to understand if Servigistics can do the service parts planning job properly and if it has been used correctly by InFocus. The actions designed to complete the first step are to experiment with the Servigistics tool and get familiar with it, attend the Servigistics software training provided by Servigistics Inc. to InFocus' planners, read Servigistics software manual and the training manual, consult Infocus' planning manager and senior planner. All the above mentioned actions have been taken and we obtained a good understanding of Servigistics software and how it is used by InFocus. We will report on this understanding in the section of "Findings".

5.2 Second major step: conduct case studies using selected service parts to identify improvement opportunities over Servigistics' outputs and simulate how much improvement can be made using better forecasting methods. We can then translate these findings into the amount of inventories that InFocus should be holding so that we can quantify the potential savings.

5.2.1 Forecasting methods:

- Seven forecasting methods are used to forecast the demands of service part in the case studies carried out and they are explained below. To provide some quick background information, the service parts are used for the repair of two types of projectors, DLP type of projector and LCD type of projectors. DLP and LCD are two types of technologies commonly found in projectors. DLP refers to Digital Light Processing and LCD refers to Liquid Crystal Display.

- Method 1 Forecast based on statistical results: it is obtained statistically that the monthly return rate of DLP type of projectors is about 0.73% of the cumulative sales and that of LCD projectors is about 0.52% because of projector failures. This is obtained by making use of the available 21 projector models and averaging their monthly return rates to get the grand average return percentage for each type of projector, be it LCD or DLP; we also find statistically that 9.71% of the time, the returned projectors would require a replacement of an engine. Hence, an estimate of the service parts needed is "9.71%*0.73%*forecasted cumulative sales" or "9.71%*0.52%*forecasted cumulative sales," depending on whether it is a LCD or DLP projector.
- Method 2 is almost the same as method 1 except for one point. The formula it uses for forecasting the service parts is "9.71%*forecasted return rates*forecasted cumulative sales" instead of using the fixed monthly return rates of 0.73% for DLP projector or 0.52% for LCD projector. The forecasted return rates are obtained based on a 3-month weighted average method by making use of the past three months' actual monthly return rates. We produce the weighted sum by assigning higher weight to the most recent month's return rate and lower weights to older months' return rates. By doing so, we are able to capture any trend in the monthly return rates.
- Method 3: method 3 is similar to method 1 except that it uses the given statistical result of 16% of the return projectors would require a replacement of an engine. Hence, the formula used for method 3 is: "16%*0.73%*forecasted cumulative sales" or "16%*0.52%*forecasted cumulative sales" depending on whether it is a LCD or DLP projector. This number, 16%, is not verified and it is provided by InFocus without any resource for verifying. That is why studies were done by making use of the available data and the result of 9.71% is obtained rather than using 16% blindly. But as the information is provided by InFocus, a corresponding forecasting method is introduced based on that and its results will be compared against those obtained by other methods.

- Method 4: this method is an improvement over method 3 as it makes use of the forecasted monthly return rates instead of the fixed value of 0.73% and 0.52%. So the formula used for method 4 is "16%*forecasted return rates*forecasted cumulative sales". Similar to method 2, the "forecasted return rates" are the weighted sum of past three months' return-rates.
- Method 5: 6-month weighted average. This is the built-in method provided by Servigistics software. It produces the forecast as the weighted sum of the past 6 months of demand and gives different weights for each month, giving highest weight to the most recent month [2]. The weight will decrease monotonically when older demands are used. For example, assume the demands in the first six months of 2006 are 10 for January, 20 for February, 30 for March, 40 for April, 50 for May and 60 for June. And assume Servigistics assigns weight 0.3 to June, 0.25 to May, 0.2 to April, 0.15 to March, 0.07 to February and 0.03 to January. Then the forecast of service part demand for July, 2006 is: $10\times0.03+20\times0.07+30\times0.15+40\times0.2+50\times0.25+60\times0.3=44.7$.
- Method 6 "3-month weighted average" method: It forecasts in the same way as the 6-month method except that it uses the past three months of demand instead of six. It also gives higher weight to the most recent month and lower weights to the older two months' demands. For example, assume the demands in the first three months of 2006 are 10 for January, 20 for February and 30 for March. Also assume that Servigistics assign weight 0.2 to January, 0.3 to February and 0.5 to March. Hence, the forecast for April, 2006 would be: $10\times0.2+20\times0.3+30\times0.5=23$. This method serves for a testing purpose and its results will be mainly compared with that of method 5 to see if some improvements can be made by varying the number of past demands used for forecasting.
- Method 7 Forecast based on linear regression model: statistical software MINITAB is used to obtain the linear regression model for service part demands based on variables that InFocus believes to be relevant in determining the service parts demands, e.g. monthly projector returns, cumulative projector returns, monthly projector sales and cumulative projector sales. For example, by inputting the above four variables into MINITAB, the output may be: y = 5.3 + 1.08 mr - 0.00596 ms + 0.0177 cr - 0.00306 cs. "y" represents the forecast service part demand for a particular month; "mr" represents the monthly return of projectors for the previous month; "ms" refers to last month's sale

of projectors; "cr" accounts for the cumulative projector returns up to previous month and "cs" shows cumulative projector sale up to previous month. Hence, the formula will be used to obtain the forecast of next month's service parts demand by making use of the four pieces of available information and the formula obtained. This method is designed to test out if there is any fixed relationship between the service parts demands and the four variables mentioned above

5.2.2 Case studies are done in a few steps with a series of objectives:

Firstly, efforts are spent on improving the current weighted average method by varying the weights or reducing the number of historical data used to 3 months. This is designed to see if any immediate and inexpensive action can be taken to improve InFocus' forecasting results. And this step is used for testing and case study purpose. More studies will be done later to obtain more results in order to have a more accurate understanding.

Secondly, we obtain a forecast based on the linear regression model and compare the results with that of the weighted average method.

Thirdly, a series of case studies are carried out to obtain the results for:

✓ Quantify current forecasting accuracy using Mean Absolute Error (MAE) as a measure; this is an important step as InFocus has not done anything in terms of quantifying their service parts forecasting accuracies.

✓ Try to improve the current forecast results using 6-month weighted average method by varying the weights; different from what has been done in the pilot case study on improving forecast results using simple measures like varying the weights or reducing the number of past records used to 3, this step is meant to get more results to confirm the conclusion made before.

✓ Try to improve the current forecast using 3-month weighted average method by adjusting the weights; this is designed to provide an easy and inexpensive opportunity to improve the forecasting result as employing the 3-month weighted average method only requires changing the number of past records to use from 6 to 3 in Servigistics;

✓ Forecast cumulative sales data using 3-month weighted average method which will be used for obtaining service parts forecasts when methods 1 to 4 are used; each month's cumulative sales data is obtained in the same way as the forecast of service part but using 3-month weighted average method; this step is designed to simulate the actual situation in which only past cumulative sales data is available and the forecast of next month's cumulative sales data needs to be obtained in order to use forecasting methods 1 to 4;

- ✓ Forecast monthly return rates using 3-month weighted average method which will be used for obtaining service parts forecasts when methods 2 and 4 are used; this step is designed to simulate the actual situation in which only past monthly return rates are available and the forecast of next month's monthly return rate needs to be done in order to use forecasting methods 2 and 4;
- ✓ Obtain forecasting accuracies for methods 1 to 6;
- ✓ Select the best two forecasting results other than the current method and simulate how inventories would have been if a "dynamic continuous review inventory management policy" were used; as the demand of service parts is a non-stationary process, we use a "dynamic continuous review inventory management policy" instead of the "continuous review policy." Each month's demand is considered to be a normally distributed process with mean and standard deviation derived from past records. The word "dynamic" reflects the fact that each month we will update the optimal order quantity, Q, reorder point, ROP, safety stock, stocking maximum and expected inventory.

  The exact formulas being used are:

1. EOQ is calculated as Q(n) = $\sqrt{\dfrac{2K \times AVG(n)}{h}}$; here, AVG(n) is the forecasted service part demand for next month and it will used as the average demand for the next three months; where K represents the fixed ordering cost; h is the monthly holding cost calculated based on annual holding cost;
2. The reorder point s, is calculated as follows:

   $s = AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$;

   Here, $AVGL(n)$ is the average lead time obtained from the past Purchase Order and Delivery Order records; $STD(n)$ is the standard deviation of the past three months' absolute deviations of forecasted service parts demand from actual service parts demands; $STDL(n)$ is the standard deviation of the past records for lead time calculated from past Purchase Order and Delivery Order records;

$AVG(n) \times AVGL(n)$ represents the forecasted average demand during lead time, while $\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$ is the forecasted standard deviation of demand during lead time;

3. The safety stock that has to be kept is equal to:

   $z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$;

4. The order-up-to level, S, is the sum of the reorder point and Q, i.e.:

   $S(n) = Q(n) + AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$

5. The expected level of inventory before receiving the order is the safety stock:

   $z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$

6. The expected level of inventory immediately after receiving the order is:

   $Q(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$;

7. Thus, the average inventory level is the average of the above two values, which is equal to:

   $Q(n)/2 + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$;

✓ The last step to take is to compile the sets of expected inventories using the current forecast method and the best two forecasting methods from the other six methods, and quantify the savings of inventories in terms of amount of service parts saved and the amount of money saved.

Chapter 6 Findings

Overview: This section reviews the analysis to understand how Servigistics does the service parts planning job and if it has been used correctly by InFocus. We examine the Servigistics tool and how it is used by InFocus qualitatively. The quantitative analysis results will be presented in the next section, "Results". To be more specific, this section explains the information that is fed into Servigistics, their accuracy and how it is actually used for forecasting and planning and generating actions needed. We also discuss the forecasting method that is specified by InFocus. After that, we review the inventory management model used by Servigistics. Finally, we evaluate whether the appropriate operation practices have been carried out by InFocus based on the "recommended actions" output from Servigistics. The results corresponding to the second major step of the approach, with the aim of improving or even optimizing service parts planning process for InFocus will be presented in the next section under "Results".

6.1 What is the Servigistics tool?

Servigistics is a Web-based planning and forecasting software for service parts management. It is part of a Service Resource Planning (SRP) solution that helps its users to better manage service parts logistics to maximize service profitability while increasing customer satisfaction and market share [3].

6.2 System integration between host inventory system and Servigistics [3]

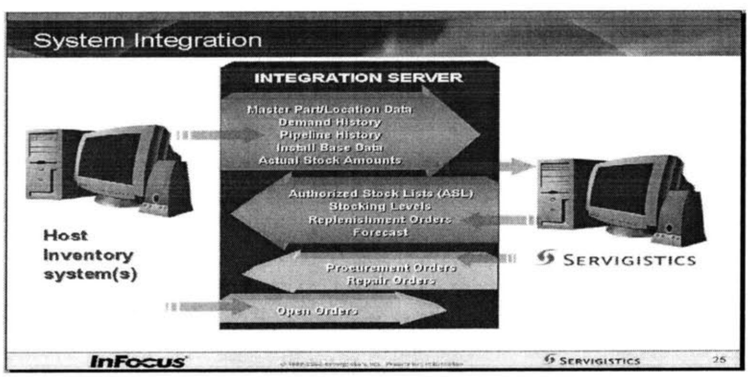

Figure 6-1 Illustration of system integration process [3]

(Picture is taken from Servigistics training manual for InFocus)

The picture above provides the clear answer to how Servigistics is integrated into the host inventory system, what information is fed into Servigistics and in return, what outputs are produced by Servigistics.

To be more specific, five important pieces of information are fed into Servigistics:

- ✓ Part and location data: it provides the paired-up information to Servigistics which explains what each part is and where it is stored;
- ✓ Demand history: it updates the actual demand history of each individual service part and this piece of information will be used for service parts forecasting;
- ✓ Pipeline history: it reviews the various lead times, e.g. procurement lead time and repair lead time, calculated from the past records. For example, the procurement lead time is calculated as the difference in days between the issue of Purchase Order (PO) and the Receive Order (RO).
- ✓ Install base data: it records the sales of each projector and it can be used to obtain the monthly return rates of the projectors and other statistics to have a better understanding of the quality of the projector and other aspects as well.
- ✓ Actual stock amounts: it reveals the actual inventory for all service parts, the amount on order, the amount under repair, the on-hand good parts and on-hand bad parts. It reflects how well the service parts inventories are being managed.

6.3 Problems with information accuracy

The previous part explains how Servigistics is integrated into the system and what kind of information is fed into it. But we found that not all the information fed into Servigistics is up-to-date. This fact seriously affects the validity of the outputs produced by Servigistics, as the information is required in calculations done by Servigistics.

The identified problems are summarized below:

- ✓ The "part repair cost" is estimated to be a quarter of the actual part cost for all service parts without providing the exact repair costs. This might be a reasonable estimation for many of the parts. However, more accurate information is always better; for instance, for some of the most expensive parts, the repair cost may differ from the estimated value by a few hundred dollars.
- ✓ The "demand history" is not completely reflected in the Servigistics database.

Servigistics was used by InFocus starting from third quarter of 2003 and demand history for almost all service parts can only be traced back to 2004; demand information before that is gone.

- ✓ The "pipeline history" is not well maintained or up-to-date and some of the pipeline records are seriously wrong. This leads to problems of undesired inventory levels and low demand satisfaction. The problem is most serious with the standard deviation of procurement lead time. As mentioned before, the procurement lead time is calculated by counting the difference in days between the Purchase Order (PO) and Delivery Order (DO). InFocus didn't pay close attention to service parts planning in the past few years; as one consequence, their procurement actions are mostly based on ad-hoc basis rather than strategic practices. To give an example, most of the engines are purchased in one shot from a contract manufacturer with the expectation to cover all of the demands throughout the projectors' service life cycle; these engines are kept at InFocus' warehouse. Because engines are the most expensive service parts, InFocus incurs a huge inventory holding cost. Although it is cheaper to order a large amount in one shot, InFocus can incur an inventory holding cost for at least two years or more, which accounts for almost 50% of the engine cost. Furthermore, because of the requirement of forecasting the total amount expected for a particular engine throughout the entire service life cycle, the forecast result will be seriously off in most cases due to the long forecasting horizon. This leads to the situation of either InFocus running out of stock and having to pay higher prices to buy additional service parts from contract manufacturer in smaller quantity, or InFocus holding excess and unnecessary inventory and paying huge amount for inventory holding cost with no good ways to dispose of the obsolete service parts.
- ✓ The "install base data" is not integrated into Servigistics system yet and it is desirable to add this piece of information into the system as a better forecasting result may be obtained by making use of the "install base data.".

6.4 The forecasting method used by Servigisitcs [3]

Servigisitcs software provides up to seven forecasting methods and InFocus has the right to use anyone that it thinks to be the most appropriate method. Currently, InFocus uses the 6-month weighted average method. It makes use of the past 6 months demand records to predict next month's demand. The forecast is a weighted sum of the past six month demands and a weight is assigned to each month decided by Servigistics, giving relatively higher weight to most recent month and lower weights to older records. Studies reveal that the weighted average method is a fairly good method to use but its result can be improved by either varying the weights or using different number of past records. Currently, the weights are generated by Servigistics and it varies from part to part. It is not very clear how Servigistics does the weight selection and there is no specific instruction or explanation on this in the Servigistics manual and the training manual. But we observed that Servigistics normally assigns a weight ranges from 0.25 to 0.3 to the most recent month; the rest of the weights are smaller and decline in a monotonic fashion.

6.5 Inventory management model

The inventory management model used by Servigistics is the "dynamic continuous review policy" with formulas that account for lead time variability. The detailed formulas are:

- ✓ EOQ is calculated as $Q = \sqrt{\frac{2K \times AVG(n)}{h}}$;
- ✓ The reorder point s, is calculated as follows:

  $$s = AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$$

  - $AVG(n) \times AVGL(n)$ represents the average demand during lead time;
  - While $\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$ is the standard deviation of demand during lead time;
- ✓ the safety stock that has to be kept is equal to

  $z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$;
- ✓ the order-up-to level, S, is the sum of the reorder point and Q, i.e.:

  $$S(n) = Q(n) + AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$$
- ✓ The expected level of inventory before receiving the order is the safety stock:

  $z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$

- ✓ The expected level of inventory immediately after receiving the order is:

  $Q(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$;

- ✓ Thus, the average inventory level is the average of the above two values, which is equal to:

  $Q(n)/2 + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$;

All of these formulas are updated from month to month as n increases whenever new demand is disclosed. The Servigistics tool does all the associated calculations internally and displays the results for planners' viewing.

6.6 Overall evaluation

- ✓ It is very obvious that InFocus didn't use the current set of forecasts scientifically, which means that they didn't plan their procurements according to current forecasts and the way Servigistics recommends on how to use the forecasts to keep the inventory at the expected value. The claim is based on the actual engine procurement practices taken by InFocus where big initial purchases are made for all the 17 engines studied. Their current inventory level is very high. We found for some service parts that their current inventory levels are almost four times the expected value to achieve the expected customer service level. Hence, whichever forecasting method is chosen, the most important thing that should be taken is to convince InFocus that we should manage our inventory scientifically. It is possible that InFocus was facing pressure given by Contract Manufacturer (CM), asking them to procure as much as they can in one shot. This provides the potential opportunity for InFocus to reconsider and negotiate a better supply chain contract with the CM. Basically, InFocus should monitor their inventory level continuously and update their ROP and Safety Stock level from month to month. Whenever the inventory goes below the ROP, actions should be taken, be it repair or procurement. Definitely the CM will not be happy with this change of ordering behavior from InFocus. But InFocus should convince the CM to cooperate, e.g. CM can pay for some share of the holding cost or InFocus can pay for some portion of the set-up cost incurred by CM.

- ✓ Also, as InFocus didn't manage their service parts planning scientifically in the past, it faces serious problems of having back-orders or large amount of excess inventories. It has to fire-fight almost everyday in order to take contingent actions to satisfy the customers' requirements. For example, in a lot of cases, InFocus has to ask the CM to deliver the products in one or two days' time; whereas for other times, InFocus has to push back CM's delivery of orders placed a few months ago as there is still excess inventories and the actual rate of inventory consumption is way below the expected level. By taking such kind of contingent actions, the lead time results and their standard deviations will be severely skewed as Servigistics calculate the lead time as the difference in days between Purchase Order and Delivery Order. These contingent actions result in the case that the Delivery Order dates do not reflect the actual time needed by CM to complete the ordered products. Hence, the AVGL(n) and STDL(n) used by Servigistics would be wrong and lead to undesired inventory levels. This problem will be worsened as this cycle repeats over time.

Chapter 7 Results

Overview: This section presents the quantitative results obtained from pilot case studies with the objective of improving the current forecasting result using simple and mathematically inexpensive measures, for example varying the weights used for getting the weighted sum forecast or change the number of past records used from 6 to 3. We also present the results of comparing forecasting results obtained by using linear regression method with that of weighted average and moving average methods. After conducting the pilot case studies, we conclude that the forecast using linear regression method will require huge amount of efforts and needs cooperation from Servigistics Inc. It needs Servigistics Inc. to develop a new built-in forecasting method specifically designed for InFocus which will cost additional amount of money and time. Hence, the methods that are practical and easy to implement, for example, forecasting using statistical results and the improved weighted average method become the focus of the project. Furthermore, the calculated Economic Order Quantity, Q, Re-order Point, ROP and Safety Stock level, SS are compared with the outputs from Servigistics to examine the Servigistics' outputs' validity. Finally, we present the results quantifying how much savings in inventories can be achieved.

7.1 Improve the weighted average method by adjusting the weights and use 3-month weighted average method

Three pilot case studies use three expensive engines and their results are presented below. The details of these three engines will not be disclosed as they are confidential to InFocus. They will be referred to as part 1, 2 and 3.

Table 7-1 Weights used by 3-month weighted average method for part 1

Set	1	2	3	4	5	6	7	8
Month-3	0.2	0.1	0.1	0.1	0.05	0.05	0.02	0.33
Month-2	0.3	0.3	0.2	0.1	0.05	0.15	0.18	0.33
Month-1	0.5	0.6	0.7	0.8	0.9	0.8	0.8	0.33

Explanation:

✓ The test data for this pilot case study is the global monthly demand history and historical forecasted demand from September, 2004 to March, 2006.

✓ All of the weight sets are selected to test out if they can improve the forecasting accuracy. All together 8 weight sets are used for service part 1. The second row, named "month-3" displays the weights that will be multiplied by the demand record three months ago. Similarly, the third row named "Month-2" shows the weights that will be multiplied by the demand record two months ago and the weights in the last row under the name "Month-1" will be multiplied by the previous month's demand. Weight set 6 and 7 are selected after obtaining the results for the first five sets and it is found that the Mean Absolute Error (MAE) is the smallest when the weight assigned to previous month's demand is around 0.8. Set 8 is selected in order to compare the method of moving average with weighted average. Moving average gives an equal weight to each of the past three months.

✓ How MAE is obtained: We assume each month's forecast is the forecasted demand for the current month, next month and two months later. For example, when we obtain the forecast for March, 2005, we assume that the demand forecast for April, 2005 and May, 2005 are also same as that of March, 2005. The forecast error for March, 2005 is obtained by using the formula (Forecast(Mar, 2005) * 3 – Actual demand(March, 2005 to May, 2005)). Hence, the calculation of current month's forecast error requires the actual demands for the next two months. The reason that we use three months' demand is that the procurement lead time for engine is three months which requires the forecast for next three months. Hence, the accuracy shall be obtained by comparing the forecast against the actual demand in three months' window. The same rule applies all the way to January, 2006 as the actual demand is available until March, 2006. So the MAE result will be up to January, 2006. We take the grand average of the absolute vbalue of all of the forecast errors obtained previously up to April, 2006 and use this value as the MAE for the set of weights selected.

Result for part 1:

Table 7-2 Result for the 3-month weighted average method for service part 1

Result set	1	2	3	4	5	6	7	8
MAE	55.91	53.59	52.58	52.23	52.91	51.20	51.21	58.72

Observation: Based on **Table 7-2**, it can be seen that forecasting accuracy can indeed be improved by varying the weights used to get the weighted sum forecast. The comparison of 3-month weighted average method to the current method and the improved version of 6-

month weighted average method will be presented later on. By referring back to the **Table 7-1**, we observe that in general, increasing the weight assigned to the most recent month, improves the forecast accuracy. This trend is reflected by observing the result sets 1 to 4 where incremental improvement was observed each time the weight for "Month-1" is increased. And the most accurate result was obtained when 0.8 was assigned as the weight for the most recent month. Also, the weighted average method is better than moving average method; each of the 7 results obtained using weighted average is better than that of moving average which is of value 58.72 presented in column "8". The figure below gives the clearer visual comparison of forecasting accuracies across different sets of weights used.

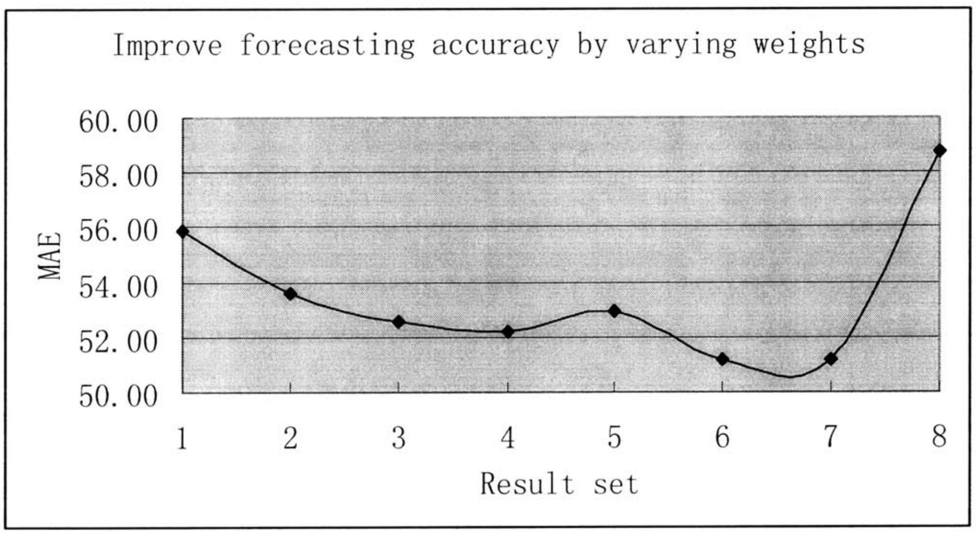

Figure 7-1 MAE result for 3-month weighted average method for service part 1

Using the same approach, case study results for service part 2 are also obtained and presented below:

Table 7-3 Weights used by 3-month weighted average method for service part 2

Set	1	2	3	4	5	6	7	8
Month-3	0.2	0.1	0.1	0.1	0.05	0.1	0.15	0.33
Month-2	0.3	0.3	0.2	0.1	0.05	0.35	0.25	0.33
Month-1	0.5	0.6	0.7	0.8	0.9	0.55	0.6	0.33

Table 7-4 Result for the 3-month weighted average method for service part 2

Result set	1	2	3	4	5	6	7	8
MAE	18.46	17.94	18.36	19.19	20.06	18.07	18.04	19.17

Observation: Similar to the first case study's results, we observe that the forecasting accuracy can indeed be improved by adjusting the weights. Slightly different from the previous case study, the most accurate result is obtained by giving the weight of 0.6 to the most recent month instead of 0.8. Hence, it is not the case that the higher the weight given to the most recent month, the more accurate the forecasting result is. But one confirmation to the first case study is that, the weighted average method can do better than the moving average in general. Again, the result summary is presented in the figure below to provide a clearer visual image.

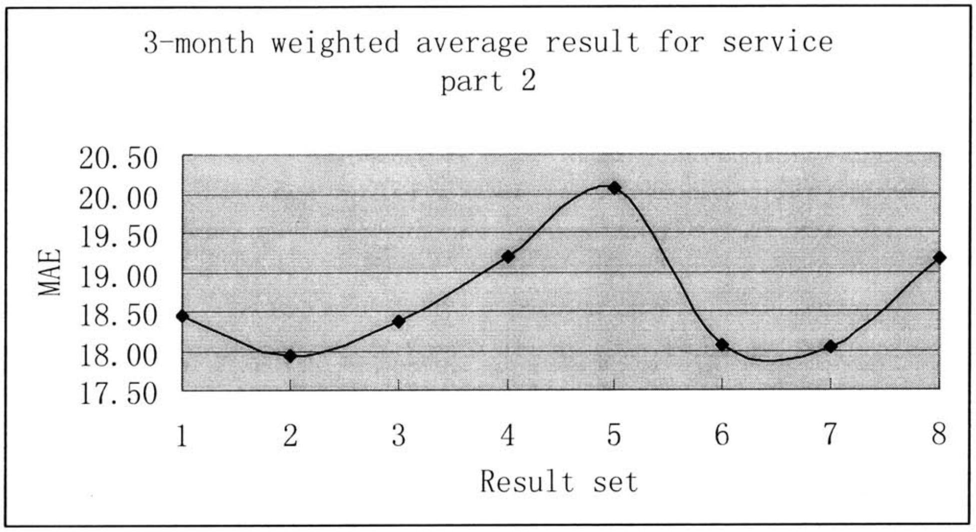

Figure 7-2 3-month weighted average results for service part 2

Similarly, the results obtained for service part 3 are presented below:

Table 7-5 Weights used by 3-month weighted average method for service part 3

Set	1	2	3	4	5	6	7	8	9
Month-3	0.337	0.2	0.1	0.1	0.1	0.05	0.05	0.05	0.33
Month-2	0.213	0.3	0.3	0.2	0.1	0.05	0.15	0.1	0.33
Month-1	0.553	0.5	0.6	0.7	0.8	0.9	0.8	0.85	0.33

Table 7-6 Result for the 3-month weighted average method for service part 3

Result	1	2	3	4	5	6	7	8	9
MAE	33.81	32.33	31.51	31.08	30.66	30.69	31.11	30.90	36.17

Observation: Again, there is a trend that giving higher weight to the most recent month, the forecasting accuracy is improved incrementally. The most accurate result is obtained when the weight given to most recent month is 0.8. Efforts trying to adjust the weights assigned to two months and three months ago fail to do better as reflected by the result 7 and 8 in **Table 7-6**. Furthermore, all the 8 sets of weighted average method's results are better than that of moving average which is "result 9" in **Table 7-6**. The plot of MAE against results is presented below for direct visualization of the effect of varying the weights.

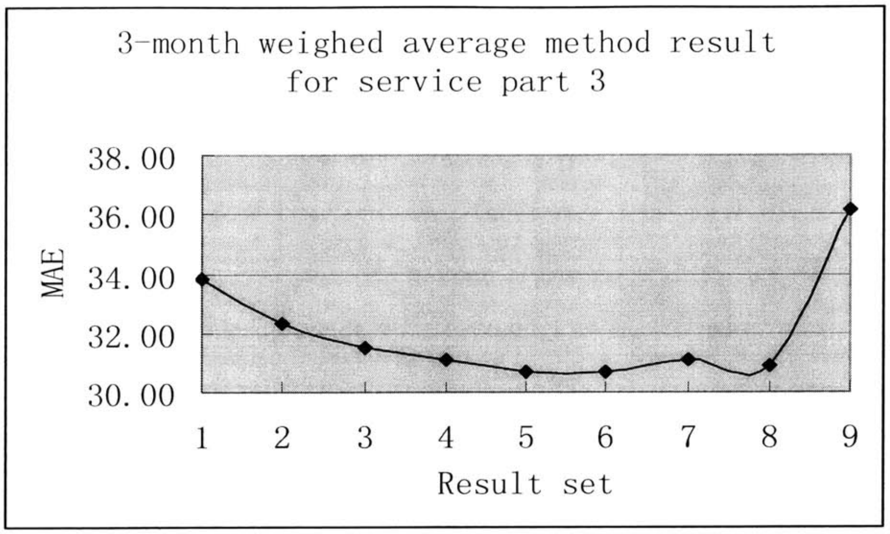

Figure 7-3 3-month weighted average results for service part 3

7.2 Improve the forecasting accuracy by using the 6-month weighed average method and adjusting the weights

Similar to the case studies carried out using 3-month weighted average method, we apply the method of 6-month weighted average to the same service parts. Hence, three sets of results are obtained. As Servigistics is also using the 6-month weighted average method, we can see whether the current forecasting results can be improved by adjusting the weights by comparing the new results with the current MAE. We calculate the MAE in the same way as described above. The detailed results are presented below:

For service part 1:

Table 7-7 Weights used by 6-month weighted average method for service part 1

Set	1	2	3	4	5	6	7	8	9	10	11
Month-6	0.07	0.02	0.02	0.02	0.04	0.02	0.025	0.025	0.01	0.01	0.17
Month-5	0.103	0.03	0.03	0.03	0.04	0.02	0.025	0.025	0.01	0.01	0.17
Month-4	0.127	0.05	0.05	0.05	0.04	0.02	0.025	0.025	0.01	0.01	0.17
Month-3	0.172	0.1	0.1	0.1	0.04	0.02	0.025	0.025	0.01	0.01	0.17
Month-2	0.232	0.3	0.2	0.1	0.04	0.02	0.4	0.3	0.26	0.16	0.17
Month-1	0.295	0.5	0.6	0.7	0.8	0.9	0.5	0.6	0.7	0.8	0.17

Table 7-8 Result for the 6-month weighted average method for service part 1

Result	1	2	3	4	5	6	7	8	9	10	11
MAE	56.37	50.77	50.99	49.14	47.22	47.24	49.41	48.26	47.07	47.09	62.68
Impr#	0	5.60	5.38	7.23	9.15	9.13	6.96	8.11	9.30	9.28	(6.31)
Impr%	0	9.93%	9.54%	12.83%	16.23%	16.20%	12.35%	14.39%	16.50%	16.46%	-11.19%

Observation and explanation:

✓ The first set of weights is what the Servigistics tool uses. The other 10 sets are designed to see if improvement over the current forecasting result can be made. The set "11" is chosen to see how the moving average method would perform when equal weights are given to all 6 months.

- ✓ In **Table 7-7**, weights in the row of "Month-1" will be assigned to the most recent month, weights under "Month-2" will be assigned to demands two month ago and this rule applies up to "Month-6" so that weights under "Month-6" will be multiplied by the demands six months ago when we try to obtain the weighted sum forecast for next month.
- ✓ In **Table 7-8**, the "Impr#" represents the improvement by the selected weight set, relative to the current setting, measured in MAE units. And "Impr%" represents the improvement expressed as a percentage of the current MAE.
- ✓ It is very obvious that when we increase the weight assigned to the most recent month from the current level, we improve the forecasting performance by having smaller MAE. This is proven by observing the results from 1 to 5 and 7 to 10 where the weight for the most recent month is increased in steps of 0.1. The best result obtained can improve the current forecasting result by 9.3 units and reduce the MAE by approximately 16.5%.
- ✓ All 10 results using weighted average method are better than that obtained using the moving average. And the MAE for moving average method is 10 units larger when compared to those of weighed average on the average. The plot of the MAE results is below.

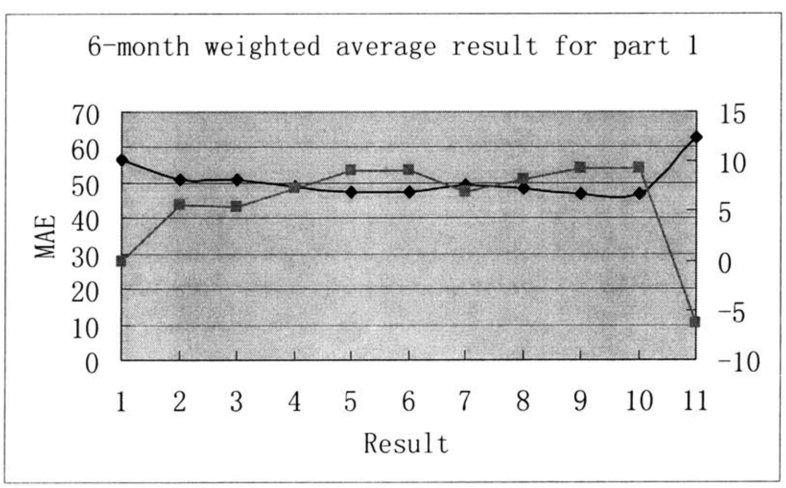

Figure 7-4 6-month weighted average results for service part 1

In the above picture, the primary axis, represented by the blue line, displays the MAE for the 11 result sets. The secondary axis, represented by the pink line, displays the improvement made by manually selected weight sets over the current method.

For service part 2:

Table 7-9 Weights used by 6-month weighted average method for service part 2

Set	1	2	3	4	5	6	7	8	9
Month-6	0.04	0.02	0.06	0.05	0.05	0.025	0.025	0.02	0.17
Month-5	0.12	0.08	0.09	0.07	0.05	0.025	0.025	0.05	0.17
Month-4	0.14	0.15	0.1	0.08	0.05	0.025	0.025	0.08	0.17
Month-3	0.19	0.2	0.15	0.1	0.05	0.025	0.025	0.1	0.17
Month-2	0.27	0.25	0.2	0.2	0.2	0.2	0.3	0.15	0.17
Month-1	0.24	0.3	0.4	0.5	0.6	0.7	0.6	0.6	0.17

Table 7-10 Result for the 6-month weighted average method for service part 2

Result	1	2	3	4	5	6	7	8	9
MAE	21.47	21.03	20.54	19.91	19.82	19.99	19.32	19.88	21.90
Impr#	0.00	0.44	0.93	1.56	1.65	1.48	2.15	1.59	-0.43
Impr%	0.00	2.05%	4.33%	7.27%	7.69%	6.89%	10.01%	7.41%	-2.00%

Observations:

✓ Again, we observe that, when the weight assigned to the most recent month is increased from 0.24 to 0.6, MAE is reduced incrementally. The largest improvement made by the new weight set is 2.15 units and 10.01% of the original result.

✓ All weighted average method results are better than that using the moving average.

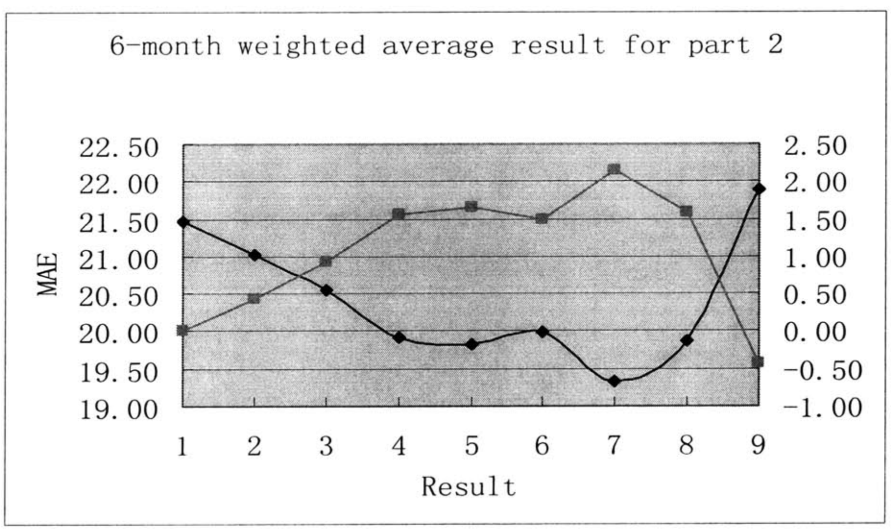

Figure 7-5 Results for 6-month weighted average method for part 2

Again, the primary axis displays the MAE results and the secondary axis displays the improvement measured in MAE units made by adjusting the weights.

For service part 3:

Table 7-11 Weights used by 6-month weighted average method for service part 2

Set	1	2	3	4	5	6	7	8	9
Month-6	0.03	0.02	0.06	0.05	0.05	0.025	0.025	0.02	0.17
Month-5	0.11	0.08	0.09	0.07	0.05	0.025	0.025	0.05	0.17
Month-4	0.13	0.15	0.1	0.08	0.05	0.025	0.025	0.08	0.17
Month-3	0.21	0.2	0.15	0.1	0.05	0.025	0.025	0.1	0.17
Month-2	0.24	0.25	0.2	0.2	0.2	0.2	0.3	0.15	0.17
Month-1	0.29	0.3	0.4	0.5	0.6	0.7	0.6	0.6	0.17

Table 7-12 Result for the 6-month weighted average method for service part 3

Result	1	2	3	4	5	6	7	8	9
MAE	42.39	42.13	39.29	36.17	34.98	35.50	36.04	34.18	48.51
Impr#	0.00	0.26	3.10	6.22	7.41	6.89	6.35	8.21	-6.12
Impr%	0.00	0.61%	7.31%	14.67%	17.48%	16.25%	14.98%	19.37%	-14.44%

Observations:

✓ Results presented in **Table 7-11** confirm the observation made in previous case studies. Forecasting result can be improved by giving higher weight to the most recent month. The best result obtained in this case study improves the current result by 8.21 units or 19.37% when compared to the current result.

✓ Again, all the results obtained using weighted average method are better than that of moving average and the difference is quite significant.

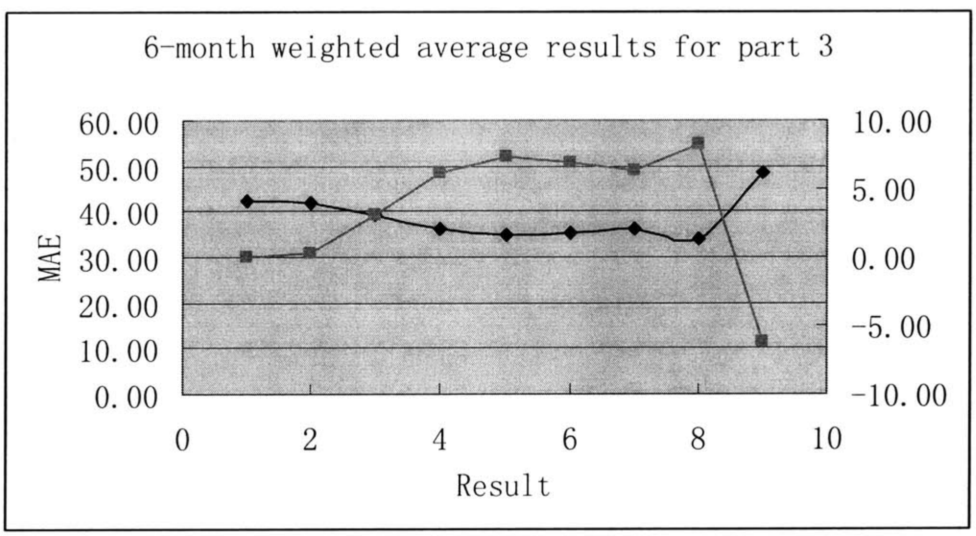

Figure 7-6 Results for 6-month weighted average method for part 3

Again, the primary axis, represented by the blue line, displays the MAE results and the secondary axis, represented by the pink line, displays the improvement measured in MAE units made by adjusting the weights.

7.3 Compare the results obtained using 6-month and 3-month weighted average methods

After conducting the case studies presented above, we compared the forecasting accuracies obtained using 3-month weighted average method and that of 6-month weighted average method for the three service parts in order to see if we can make any concrete conclusion over which method is better. The comparison results are presented below.

For service part 1:

Table 7-13 Results comparison for 3-month and 6-month methods for part 1

MAE	1	2	3	4	5	6	7	8	9	10	11
3-month	55.91	53.59	52.58	52.23	52.91	51.20	51.21	58.72	NA	NA	NA
6-month	56.37	50.77	50.99	49.14	47.22	47.24	49.41	48.26	47.07	47.09	62.68

For service part 2:

Table 7-14 Results comparison for 3-month and 6-month methods for part 2

MAE	1	2	3	4	5	6	7	8	9
3-month	18.46	17.94	18.36	19.19	20.06	18.07	18.04	19.17	NA
6-month	21.43	21.03	20.54	19.91	19.82	19.99	19.32	19.88	21.90

For service part 3:

Table 7-15 Results comparison for 3-month and 6-month methods for part 3

MAE	1	2	3	4	5	6	7	8	9
3-month	33.81	32.33	31.51	31.08	30.66	30.69	31.11	30.90	36.17
6-month	42.39	42.13	39.29	36.17	34.98	35.50	36.04	34.18	48.51

Observation and explanations:

- ✓ The cells filled with "NA" indicate that there was not a test setting for those trials.
- ✓ No concrete conclusions can be drawn over which method is better as the forecasting accuracies obtained using the two methods are comparable and are very close. We obtained the best forecast using a 6-month method for service part 1 whereas we found the best forecast with a 3-month method for service parts 2 and 3. However, you should observe that in either case you can outperform the current settings.
- ✓ We note that the 3-month method can also be regarded as 6-month method with zero weight on months 4, 5 and 6;

7.4 Forecasting method using linear regression model and results comparison with weighted average method

Two case studies were carried out using statistical software MiniTab for gaining understanding about forecasting using a linear regression model and identifying any factor that is important in determining the service part demands. Variables that are believed to be important in determining the service parts demands are used in building the linear regression model. The first case study makes use of monthly and cumulative information. The second case study makes use of quarterly and cumulative information in order to be in line with the selected service part's procurement lead time. For both case studies, the full model is initially built using all selected variables. Once we identify the corresponding levels of importance for these variables based on Analysis of Variance (ANOVA) results, we build a reduced model using the two most important variables with the objective of understanding what kind of results could be obtained using simpler model when compared to the full model's result. Again, for confidentiality reason, the parts' details are not released here and the two case studies are referred to as case study A and B.

For case study A:

Definition:

y: the actual monthly service part A demands

mr: monthly returns of projectors using selected part

ms: monthly sales of projectors using selected part

cr: cumulative returns of projectors using selected part

cs: cumulative sales of projectors using selected part

Assumption: In order to simplify the analysis, we assume that the full ranges of the four variables are known when we use MiniTab software to obtain the linear regression model. That is, all the past records for monthly returns, cumulative returns, monthly sales and cumulative sales are input into MiniTab to build up the linear regression model.

This does not simulate the actual case. In reality, information of the four variables will be known little by little as time progresses. Hence, the linear regression model would be continuously updated whenever new information is available. But as the objective of this study is to identify the significant factors and compare the results obtained using linear regression model with that of other methods, the assumption of complete information is made to simplify the problem. After inputting the four variables, the linear regression model output by MiniTab is:

y = 5.3 + 1.08 mr - 0.00596 ms + 0.0177 cr - 0.00306 cs

The P-value test results reveal the importance of each variable. We report these values in the table below:

Table 7-16 P-value results summary for all factors

Predictor	Constant	mr	ms	cr	cs
P	0.888	0.000	0.064	0.025	0.001

Observation: According to the statistics rule, the smaller the P-value, the more important the factor is. Based on **Table 7-16** , "mr", or "monthly projector returns" is the most important factor, followed by "cumulative projector sales" or "cs", and "cumulative projector returns" or "cr." The least important factor is "monthly projector sales" or "ms". It is reasonable that "monthly projector returns" is the most important factor as the actual demand for parts is largely dictated by the parts needed to repair the returned projectors. But in reality, the actual return of projectors would be difficult to forecast as it is a function of a few factors, for example, the quality of projectors, the actual installed base and even the geographical factor, indicating where the projectors are sold and being used. Hence, a second model, a reduced version, is built using the cumulative sales and monthly sales to see how good or bad the result would be using fewer variables. After inputting the monthly sales and cumulative sales into MiniTab, the output linear regression model is:

y = 8.9 - 0.00408 ms + 0.000713 cs

The P-values are summarized and presented below

Table 7-17 P-value results summary for monthly sales and cumulative sales

Predictor	Constant	ms	cs
P	0.872	0.285	0.09

According to the table above, "cumulative sales" factor is much more important than the monthly sales. The MAE results for both the full model and reduced model are obtained and presented below.

Table 7-18 MAE for full and reduced models

Model	Full	Reduced
MAE	41	62

To obtain the MAE for both models is, we use the linear regression model to forecast each month's service part demands and this forecast is compared against the actual demand to obtain the difference, named the absolute deviation or error. Then we take the grand average of all the absolute errors to obtain the MAE for each model. The result summary displaying actual demand, fitted value and absolute error are presented below for illustration purpose.

Table 7-19 Result summary for full linear regression model

Obs	y	Fit	Absolute error
Mar-03	0	-26	26
Apr-03	1	19.9	18.9
May-03	1	-9.2	10.2
Jun-03	1	0.5	0.5
Jul-03	6	25	19
Aug-03	4	-38.4	42.4
Sep-03	8	55.7	47.7
Oct-03	21	41.3	20.3
Nov-03	21	28.1	7.1
Dec-03	46	3.3	42.7
Jan-04	23	10.2	12.8
Feb-04	30	81.9	51.9
Mar-04	49	15.8	33.2
Apr-04	29	-3.7	32.7
May-04	24	26.3	2.3
Jun-04	18	100.8	82.8
Jul-04	50	113	63
Aug-04	38	75	37
Sep-04	86	93.7	7.7
Oct-04	221	92.2	128.8
Nov-04	206	194.9	11.1
Dec-04	174	177.2	3.2
Jan-05	157	189.5	32.5
Feb-05	327	208.5	118.5
Mar-05	290	320.9	30.9
Apr-05	424	212.3	211.7
May-05	76	121.6	45.6
Jun-05	66	161.9	95.9
Jul-05	58	108.3	50.3
Aug-05	33	60.4	27.4
Sep-05	18	62.4	44.4
Oct-05	26	25.7	0.3
Nov-05	27	71.8	44.8
Dec-05	30	50.5	20.5
Jan-06	22	25.5	3.5
Feb-06	14	-36.2	50.2
Mar-06	23	-12.3	35.3
		Mean	41

The results obtained using the full linear regression model and the reduced model are compared with that of using the weighted average and moving average methods for the same service part and summarized below.

Table 7-20 Comparison of linear regression with 3-month weighted method

Result set	1	2	3	4	5	6	7	8	9	LRF	LRR
AME	59.71	55.91	53.59	52.58	52.23	52.91	51.20	51.21	58.72	41	62.00

Table 7-21 Comparison of linear regression with 6-month weighted average

Result set	1	2	3	4	5	6	7	8	9	10	11	LRF	LRR
AME	56.37	50.77	50.99	49.14	47.22	47.24	49.41	48.26	47.07	47.09	62.68	41	62.00

Observation:

The full linear regression model provides the best forecasting result compared to that of weighted average and moving average based on the results presented in both **Tables 7-20** and **7-21**. The column "LRF" and "LRR" refer to "linear regression full model" and "linear regression reduced model" respectively. Result set 9 in **Table 7-20** and 11 in **Table 7-21** are the results for moving average based on 3-month and 6-month window respectively. Result set from 1 to 8 in **Table 7-20** and from 1 to 10 in **Table 7-21** are the results obtained using weighted average method. We see that the moving average method is the worst method among the three used. Furthermore, the weighted average method's results are comparable to that using linear regression model. Even though it appears that linear regression model may provide the best result, we shall not forget the important point that when we simulate the forecasting process, we apply the weighted average method as it would work in a real context. That is, we only use the information that would be available at the time before the forecasting point to generate the current month or quarter's forecast. In contrast, for the case of linear regression model, we assume that complete information was available at the time of building up the linear regression model and the complete information was used to build up the model. Also, it is more tedious to use the linear regression model in the real context as linear regression model would need to be continuously updated and then used for generating new forecasts. The formulas used for the weighted average method would remain the same and we would only have to update the data used for generating the forecast.

As the lead time for the selected service part is 3 months, every time a forecast is generated, it shall cover the next three months. Hence, we conducted case study B using linear regression method, using quarterly and cumulative information for building up the model.

For case study B:

Definition:

qd: the actual quarterly part B demands

qr: actual quarterly return of projectors using the selected part B

qs: actual total quarterly sale of projectors using the selected part B

avgqs: actual average of quarterly sales of projectors using the selected part B cs: cumulative sale of projectors using the selected part B

Assumption: Again, to simplify the problem, we assume that the complete information for the five variables is available when we use MiniTab to build the full linear regression model. The complete information is input into MiniTab and the linear regression model obtained is:

qd = 106 - 228 qs + 0.836 qr + 685 avgqs - 0.00484 cs

Table 7-22 P-value results summary for all factors

Predictor	Constant	qs	qr	avgqs	cs
P	0.422	0.967	0.002	0.967	0.023

Observation: Based on the p values, "qr", the quarterly return of projectors is the most important factor in determining the quarterly demand of selected service part, followed by "cs", cumulative projector sales; "qs", quarterly projector sales and "avgqs", the average quarterly projector sales are of same importance. This is consistent with the results obtained in Case study A. The result summary for the full model is presented below.

Table 7-23 Result summary for quarterly demand full regression model

Obs	qd	Fit	Absolute error
Q103	0	2.9	2.9
Q203	3	9.9	6.9
Q303	18	62.9	44.9
Q403	88	1.5	86.5
Q104	102	75.1	26.9
Q204	71	201.5	130.5
Q304	174	430.8	256.8
Q404	601	529.9	71.1
Q105	774	669.9	104.1
Q205	566	437.2	128.8
Q305	109	195.2	86.2
Q405	83	95.8	12.8
Q106	59	0	59
		Mean	78

A second analysis using the two most important factors to build a reduced model is conducted and the linear regression model obtained using MiniTab is:

qd = - 122 + 0.716 qr - 0.00271 cs

Table 7-24 P-value result for "qr" and "cs"

Predictor	Constant	qr	cs
P	0.348	0.009	0.202

Again, the results using the reduced model are obtained and summarized and presented below:

Table 7-25 Result summary for quarterly demand reduced regression model

Obs	qd	Fit	Absolute error
Q103	0	-109.7	109.7
Q203	3	-15.4	18.4
Q303	18	73.1	55.1
Q403	88	207.7	119.7
Q104	102	294.2	192.2
Q204	71	331.1	260.1
Q304	174	362	188
Q404	601	437.6	163.4
Q105	774	557.1	216.9
Q205	566	361.7	204.3
Q305	109	151.2	42.2
Q405	83	67.4	15.6
Q106	59	0	59
		Mean	127

Observation: As expected, the quarterly projector return is more important than the cumulative projector sales, and the error is larger. We expect that the accuracy for the quarterly regression model is worse than that of monthly model as errors will be larger when we try to forecast for a longer horizon. We also need to compare this with those obtained using other forecasting methods, for example, weighted average and moving average methods, to draw the final conclusion.

Table 7-26 Comparison of linear regression with weighted average method

Data set	1	2	3	4	5	6	7	8	LRF	LRR
E[abs error]	179	176.5	174	171.5	169	166.75	169.13	134.99	78	127

Explanation and observation: the data sets 1 to 6 are obtained by using the method of weighted average of the past two quarters and varying the weights assigned to them. Data set 7 is based on 3-month weighted average method and sum up the monthly MAEs to get each quarter's MAE. Data set 8 is obtained similarly to data set 7 but it makes use of the results of 6-month weighted average method. "LRF" and "LRR" stand for "linear regression full model" and "linear regression reduced model" respectively. Key observations are summarized below:

- ✓ Linear regression models are better than the weighted average method when we deal with quarterly demand forecasting. But the weighted average method's results are comparable to those obtained using linear regression model when we deal with monthly demand forecasting. The longer the forecasting horizon, the worse the forecasting result.

- ✓ When we use the past quarterly demand to forecast the future quarterly demand directly, the larger the most recent month's weight is, the better the forecasting result.
- ✓ Forecasting using the linear regression model is too involved to be implemented for practical planning process as the regression model must be re-run each time we get a new demand observation.
- ✓ Using the forecast of next month's demand as the average demand for the next three months produces a more accurate result compared to the method of directly forecasting each of the next three months' demand using the past two quarters' demands.

7.5 Complete case studies on service parts planning

This section corresponds to what has been presented in the third part of the "Approach" section 5.2.2 where a series of case studies are carried out to quantify the current forecasting accuracy, seek improvement opportunities using weighted average method, simulate what would the forecasts be when various forecasting methods are used and translate the results into inventory management and the corresponding inventories levels. We present the detailed results for one service part for a better understanding when necessary. We follow this by the consolidated results that were carried out for 17 case studies.

7.6 Quantify the current forecasting accuracy

Table 7-27 Current forecasting accuracy for 17 service parts

Result	1	2	3	4	5	6	7	8	9
MAE	44	32	328	74	104	94	55	225	252
MAE/D	22.11%	27.19%	53.84%	58.78%	54.64%	26.93%	113.23%	162.81%	93.11%

Table 7-28 Current forecasting accuracy for 17 service parts

Result	10	11	12	13	14	15	16	17	Avg
MAE	15	48	58	46	130	78	14	169	134
MAE/D	28.68%	134.79%	84.18%	77.58%	42.45%	48.16%	45.14%	27.35%	68.07%

Explanation and observations:

- ✓ We conducted 17 case studies, each for a different engine. These engines are selected as they are the most expensive service parts and they will have the greatest impact on inventories.
- ✓ The table above reports the accuracy of the current forecasting method for each selected service part in the second row under "MAE". We present the relative size of MAE over the actual demand in the third row under "MAE/D;" we will explain its calculation later. The average values for MAE and MAE/D across all the 17 parts are

presented in **Table 7-28**.

- ✓ We compute the MAE for each service part as described before. That is, the current month's weighted sum forecast will be used as the average forecasted demand for the following three months and this value will be compared with the actual demand for the next three months and the difference between the two numbers will be recorded as the current month's forecast error. For example, the forecast error of Jan, 2006 is obtained by calculating MAE (Jan, 2006) = "Forecast (Jan, 2006) * 3 – Demands (Jan to Mar, 2006)". The grand average is taken to get the overall MAE for each service part and presented in the second row under "MAE" in **Table 7-27 and 7-28**.

The formula used is $\frac{\sum_{n=1}^{N} MAE(n)}{N}$ where the index n refers to individual month and N denotes the number of months in the data base.

- ✓ As the size of each service part's demand will be different throughout the case studies and larger demands tend to have larger MAE, presenting MAE alone is not sufficient to have a good sense of how accurate the forecasting result is. Hence, we report the "MAE/D", which is the grand average of "monthly MAE divided by demands of next three months" for each service part. The formula used for obtaining "MAE/D" for each service part is:

- ✓ $MAE/D = \frac{\sum_{n=1}^{N} MAE(n)/Demands(n,n+1,n+2)}{N}$ and the index n refers to individual month and N denotes the number of months in the data base.

The reason that "MAE/D" is calculated as monthly MAE divided by next three months' demands is due to how MAE is obtained. Hence, by doing so, a better understanding of the significance of MAE relative to actual demands is obtained.

- ✓ We observe that, the "MAE/D" value fluctuates quite a bit across the 17 service parts. The overall average is 64.76%. Some of the parts have "MAE/D" values ranging from 20% to 50%. Some parts have less accuracy by having large "MAE/D" above 70% or even 100%. The fluctuation is due to a number of factors, probably projector quality, actual installed base or where the projectors are sold and used.

7.7 Improve the current forecasting results using weighted average method

Table 7-29 Improvement made using weighted average method

Result	1	2	3	4	5	6	7	8	9
Impr% by 3	35.96%	4.18%	57.79%	38.86%	13.52%	19.74%	58.16%	65.05%	56.49%
Impr% by 6	48.41%	6.98%	64.27%	43.65%	2.00%	22.86%	55.00%	69.96%	58.13%

Table 7-30 Improvement made using weighted average method

Result	10	11	12	13	14	15	16	17	Avg
Impr% by 3	27.81%	39.02%	58.21%	61.24%	40.33%	35.77%	15.03%	16.13%	38.86%
Impr% by 6	11.18%	31.79%	59.40%	54.23%	45.35%	39.08%	0.34%	4.50%	41.25%

Observations and explanations:

- ✓ We present two sets of results, which represent the improvement made by a 3-month weighted average method and that of a 6-month weighted average method. We report the "reduction in MAE divided by current MAE*100%" for each of the 17 selected parts. For instance for part 1, we report the improved MAE for 6-month weighted average to be 13.93 and the current MAE result is 27. Hence, the reduction in MAE is 27 – 13.93 = 13.03. So "Impr% by 6" is obtained by dividing 13.03 by 27 and the result is 48.41%. Similarly, 17 sets of "Impr% by 3" and "Impr% by 6" are obtained and presented in the table above.
- ✓ We observe that improvement can be made using either weighted average method across all 17 case studies.
- ✓ 3-month and 6-month weighted average method can make comparable improvement over the current result which can be shown by the average improvement made using either method.
- ✓ By simply adjusting the weights used to obtain the weighted sum forecasts, forecasting accuracy can be improved by approximately 37% on the average. The weights are selected by trial-and-error. We basically increase the weight assigned to the most recent month in steps of 0.1 and observe if the resulted MAE increases or decreases. If the MAE decreases, we will increase the highest weight again. For example, we will start with assigning 0.5 as the most recent month's weight. If the MAE decreases, the weight will be increased to be 0.6. This process will continue until the obtained MAE increases rather than decreases. Then the weight set offers the least MAE will be selected. A second step will be taken to try to minimize the MAE using the selected set. The most recent month's weight will be kept constant as before. Whereas efforts will be spent on adjusting the other weights to see if

improvement can be made. The set that offers the least MAE will be finally obtained.

7.8 Forecasting using 6 methods and obtain MAE for each method

After quantifying the current forecasting accuracy and verifying improvement opportunities over the current method, the next step is to simulate forecasting results using selected forecasting methods, i.e. forecasting based on statistical results and forecasting using weighted average method. The 6 methods being used here are described in "Approach" section 5.2.1 in details. Here, one service part's forecasting results using 2 methods, method 1 and 2 are presented below to give an illustration of how the simulation of the planning process was done in all the 17 case studies and the service part is referred to as part X.

Table 7-31 Forecasting result using method 1 for part X

Month	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06
FCS	138855	138870	138870	138873	138875	138875	138880	138881	138881	138881	138885	138885	138885	138885	138885	138885	138885
FD	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98	98
QD	295	295	295	295	295	295	295	295	295	295	295	295	295	295	295	295	295
MAE	131	11	29	127	129	127	32	61	132	159	190	177	189	202	227	236	238

Explanation and observations:

- ✓ The forecasting process simulates the period from Sep, 2004 to Jan, 2006 due to data availability. The formula used for this part X in method 1 is:

  "Forecasted demand = 9.71%*0.73%*forecasted cumulative sales".
- ✓ Definitions:
  - ■ FCS: forecasted cumulative projector sales;
  - ■ FD: forecasted part X demand for the month;
  - ■ QD: forecasted quarterly part X demand, which is obtained by "FD*3";
  - ■ MAE: mean absolute error.
- ✓ The MAE for part X using method 1 is 141.

Table 7-32 Forecasting result using method 2 for part X

Month	Sep-04	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06
FCS	138,855	138,870	138,870	138,873	138,875	138,875	138880	1388809	138881	138881	138885	138885	138885	138885	138885	138885	138885
FR	0.71%	0.89%	0.87%	0.87%	1.07%	1.19%	1.52%	1.48%	1.16%	1.24%	1.25%	1.07%	1.01%	0.83%	0.91%	0.78%	0.55%
FD	96	120	117	117	144	160	205	200	156	167	169	144	136	112	123	105	74
QD	287	360	352	352	433	481	615	599	469	502	506	433	409	336	368	316	223
MAE	123	76	28	70	9	59	288	365	306	366	401	315	303	243	300	257	166

Explanation and observations:

- ■ Definitions:

  - The only additional term here is "FR": forecasted projector return rates using part X;
- The formula used for method 2 is:
  9.71%*forecasted return rates*forecasted cumulative sales.

All 6 methods are applied to the 17 parts and the corresponding MAEs are all obtained and consolidated in the table below.

Table 7-33 Forecasting accuracies for 17 parts using 6 methods

MAE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Avg
Current	44	32	328	74	104	94	55	225	252	15	48	58	46	130	78	14	169	104
Method1	49	71	299	133	165	68	55	141	114	34	58	50	79	211	186	12	282	118
Method2	83	71	456	124	171	61	28	216	116	30	54	54	20	278	176	12	463	142
Method3	28	62	173	124	132	51	132	280	167	25	49	145	182	132	162	14	124	117
Method4	76	61	386	109	141	40	26	476	328	21	42	20	24	234	144	26	402	150
Method5	42	30	117	42	101	82	24	67	106	14	32	22	13	69	57	14	181	60
Method6	52	36	139	46	89	84	23	79	110	19	29	31	18	74	50	16	157	62

Explanation and observations:

- All MAEs using 6 proposed methods are consolidated together with the current MAE for all 17 parts; The formulas used for the 6 methods are:
  - Method 1: 9.71%*0.73%*forecasted cumulative projector sales;
  - Method 2: 9.71%*forecasted projector return rates*forecasted cumulative projector sales;
  - Method 3: "16%*0.73%*forecasted cumulative projector sales" or "16%*0.52%* forecasted cumulative projector sales" depending on whether it is a LCD or DLP projector;
  - Method 4: 16%*forecasted projector return rates*forecasted cumulative projector sales;
  - Method 5: 6-month weighted average method using manually selected weights;
  - Method 6: 3-month weighted average method using manually selected weights;
- We observe that Method 5 and 6 offer the least MAEs on the average which indicates that weighted average method is the best.

7.9 Simulate desired inventory management process using current forecasting result and two other best forecasting results

After quantifying the forecasting accuracies for all 17 parts using the selected 6 methods, we use the current method and the two other methods that offer the least MAEs to simulate the inventory management process throughout the planning window. Again, for illustration purpose, the inventory management simulation result for part X using method 5, 6-month weighted average method are presented below for illustration and better understanding.

Table 7-34 Inventory management simulation result for part X using method 5

Month	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06	Avg
Q	80.65	82.78	68.02	54.88	56.83	42.30	41.26	41.78	44.81	32.37	33.69	52.67
SS	171.62	237.21	120.21	160.89	180.05	32.50	87.20	84.89	88.19	12.46	10.82	107.82
ROP	618.62	708.21	438.21	367.89	402.05	155.50	204.20	204.89	226.19	84.46	88.82	318.10
SMAX	699.27	790.99	506.23	422.77	458.89	197.81	245.46	246.68	271.00	116.82	122.51	370.77
AVGMD	149.00	157.00	106.00	69.00	74.00	41.00	39.00	40.00	46.00	24.00	26.00	70.09
STD[MAE]	60.05	83.00	42.06	56.30	63.00	11.37	30.51	29.70	30.86	4.36	3.79	37.73
E[inv]	211.95	278.60	154.22	188.33	208.47	53.65	107.83	105.78	110.60	28.64	27.66	134.16
E[inv]$	$117,736	$154,763	$85,671	$104,617	$115,806	$29,804	$59,900	$58,763	$61,438	$15,910	$15,367	$74,525

Explanation and observations:

- Definitions:
  - Q: Economic order quantity, Q(n) = $\sqrt{\dfrac{2K \times AVG(n)}{h}}$;
  - SS: safety stock, $z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL^2(n)}$;
  - ROP: reorder point:

    $$s = AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$$
  - SMAX: stock maximum which is equivalent to sum of ROP and Q:

    $$S(n) = Q(n) + AVG(n) \times AVGL(n) + z\sqrt{AVGL(n) \times STD(n)^2 + AVG(n)^2 \times STDL(n)^2}$$
  - AVGMD: average monthly demand of part X which is the forecast of next month's demand;
  - STD[MAE]: standard deviation of three months' MAE and it is used for the calculation of safety stock;
  - E[inv]: expected inventories in units;
  - E[inv]$: expected inventories in dollars;

The inventory management simulation results using current forecasting method and the second best forecasting method are also obtained for part X and the other 16 service parts but the results will not be presented here. We will compare the results with the current inventory levels and quantify the amount of savings in each month for all 17 parts.

7.10 Compare the calculated results with the outputs from Servigistics

This step is taken with the objective of examining the validity of the results output from the Servigistics tool. This is a critical step as it helps to resolve the doubt of where the high inventory cost comes from, be it wrong outputs from the Servigistics tool or InFocus did not follow the recommendations given by Servigistics or both. This study is done using all the 17 selected service parts and the results are presented below:

Table 7-35 Comparison of calculated results with those from Servigistics

Model	1	2	3	4	5	6	7	8	9
CalQ	35.27	19.23	119.09	49.62	31.71	58.56	40.79	70.84	88.55
ServQ	13	3	1	1	6	1	11	1	1
Qdiff%	63.14%	84.40%	99.16%	97.98%	81.08%	98.29%	73.03%	98.59%	98.87%
CalSS	60.28	51.32	401.81	78.72	112.18	139.45	47.42	198.75	339.41
ServSS	36	13	0	0	32	0	0	0	0
SSDiff%	40.28%	74.67%	100.00%	100.00%	71.47%	100.00%	100.00%	100.00%	100.00%
CalROP	147.49	120.25	1404.01	257.32	202.11	394.67	169.88	593.66	917.04
ServROP	62	26	63	10	74	115	2	18	40
ROPDiff%	57.96%	78.38%	95.51%	96.11%	63.39%	70.86%	98.82%	96.97%	95.64%

Table 7-36 Comparison of calculated results with those from Servigistics

Model	10	11	12	13	14	15	16	17	Average
CalQ	30.27	36.4	46.84	40.78	82.05	65.85	24.08	86.2	
ServQ	1	1	1	1	1	1	1	45	
Qdiff%	96.70%	97.25%	97.87%	97.55%	98.78%	98.48%	95.85%	47.80%	89.70%
CalSS	29.19	57.06	71.63	42.31	105.05	67.94	20.94	163.03	
ServSS	0	0	0	0	0	0	0	206	
SSDiff%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	-26.36%	85.89%
CalROP	92.57	153.06	229.96	160.98	578.23	369.03	61.41	691.66	
ServROP	14	4	30	15	64	30	26	385	
ROPDiff%	84.88%	97.39%	86.95%	90.68%	88.93%	91.87%	57.66%	44.34%	82.14%

Explanations and observations:

✓ **Table 7-35** and **7-36** present the comparison results of Economic Order Quantity, Safety Stock and Re-order Point between the calculated values and those output by Servigistics across all the 17 selected service parts. The calculated values are obtained by making use of the past demand records and applying the formulas presented in the "Approach: section. The outputs by Servigistics are obtained from Servigistics tool. The average values of the differences measured by percentage of the calculated values are presented in **Table 7-36**.

✓ Definitions:

- CalQ: calculated or theoretical Economic Order Quantity obtained using past demand data;

- ServQ: EOQ calculated by Servigistics;
- Qdiff%: measures the difference between the calculated Q and that output by Servigistics as a percentage of the theoretical EOQ obtained through manual calculation using the past demand data;
- CalSS: calculated or theoretical Safety Stock level, or SS, obtained through manual calculation using past demand data;
- ServSS: safety stock level output by Servigistics;
- SSDiff%: measures the difference between the calculated SS and that output by Servigistics as a percentage of the theoretical SS obtained through manual calculation using the past demand data;
- CalROP: calculated or theoretical Re-order Point level, or ROP, obtained through manual calculation using past demand data;
- ServROP: re-order point level output by Servigistics;
- ROPDiff%: measures the difference between the calculated ROP and that output by Servigistics as a percentage of the theoretical ROP obtained through manual calculation using the past demand data;

✓ We observe that there are large discrepancies for all three values studied, be it EOQ or SS or ROP as the average differences account for more than 80% of the expected or calculated values..

- The average difference in EOQ is 89.70%. This occurs mainly because for 12 out of 17 service parts studied, the Q values from Servigistics are 1, which deviates greatly from the computed EOQ obtained by applying the formulas to the past demand data. The wrong output from Servigistics is due to either the actual past demand is not available in Servigistics or the information present in Servigistics database is wrong. Servigistics will output Q as 1 by default in either case when it does not have the necessary data input.
- The average difference in SS is 85.89%. The great discrepancy comes from 13 out of 17 parts are reported to have 0 safety stock according to Servigistics. The output of 0 safety stock is not because the expected customer service level is 0.5 where no safety stock is required. But either the information of procurement lead time is not

available or it is inaccurate and Servigistics will set the safety stock to zero by default as it does not have the necessary data inputs.

- The average difference in ROP is 82.14%. The discrepancy can be mainly accounted by the inaccuracy of SS from Servigistics as ROP is calculated as the sum of SS and expected demand over the expected procurement lead time.

✓ In short, we can conclude that the results output from Servigistics are wrong and failed to reflect the accurate results which will be used as the basis for recommended actions.

7.11 Quantify the amount of savings following the proposed inventory management process using current forecasting result and two other results

We illustrate the amount of savings using method 5 for part X below. The overall reductions achieved for all 17 parts will be presented later.

Table 7-37 Inventory savings for part X using method 5

Month	Mar-05	Jun-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06	Expectation
Current(#)	519	575	663	651	610	613	617	607
Current($)	$288,030	$319,319	$368,296	$361,630	$338,855	$340,521	$342,743	$337,057
Method5(#)	211.95	188.33	107.83	105.78	110.6	28.64	27.66	112
Method5($)	$117,736	$104,617	$59,900	$58,763	$61,438	$15,910	$15,367	$61,962
Reduce#	307	387	555	545	499	584	589	495
Reduce$	$170,294	$214,702	$308,396	$302,867	$277,417	$324,611	$327,376	$275,095

Explanation and observations:

- The months chosen are based on what are available in the inventory records so that comparisons can be carried out.
- Definitions:
  - Current(#): the amount of part X in inventory in each particular month;
  - Current($): the inventory for part X measured in dollars in each particular month;
  - Method 5(#): what is expected to be in inventory when forecasting method 5 is used in each particular month;
  - Method 5($): how much is the expected inventory worth using forecasting method 5 in each particular month;
  - Reduce#: savings of part X measured in units;
  - Reduce$: savings of part X in dollars;
- We observe that for this part X alone, the amount of savings can be as high as USD 0.3 million if appropriate inventory management practices are carried out.

The savings for all 17 parts are consolidated and presented below:

Table 7-38 Inventory savings for parts 1 to 9 based on 3 forecasting results

Result	1	2	3	4	5	6	7	8	9
CurrentR#	54	181	799	309	49	400	476	439	414
CurrentR$	$22,097	$159,065	$399,395	$339,442	$32,334	$269,275	$309,452	$243,845	$289,495
MethodAR#	72	180	898	377	-44	326	450	495	553
MethodAR$	$29,179	$158,300	$449,034	$414,735	($29,164)	$219,638	$292,625	$275,095	$386,785
MethodBR#	55	189	784	309	-29	366	443	463	527
MethodBR$	$22,487	$166,610	$392,131	$339,976	($18,916)	$246,281	$299,310	$257,113	$369,072

Table 7-39 Inventory savings for parts 10 to 17 based on 3 forecasting results

Result	10	11	12	13	14	15	16	17	Avg	Sum
CurrentR#	16	87	353	228	656	250	308	409	347	5,775
CurrentR$	$23,848	$172,245	$252,284	$119,978	$423,667	$189,361	$229,813	$182,607	$229,378	$3,887,581
MethodAR#	15	92	398	232	629	252	143	428	367	5,863
MethodAR$	$23,095	$180,854	$284,452	$121,915	$406,662	$190,398	$122,921	$191,168	$244,025	$3,961,717
MethodBR#	15	97	364	221	560	226	301	295	345	5,531
MethodBR$	$22,551	$191,205	$260,394	$116,067	$361,883	$170,705	$225,543	$131,586	$230,452	$3,784,450

Explanation and observations:

- Definitions:
  - CurrentR#: savings based on current inventory management method measured in units. This value is obtained by obtaining the difference between the expected inventory using the current forecasting method and actual inventory.
  - CurrentR$: savings based on current inventory management method measured in dollars;
  - MethodAR#: savings based on Method A inventory management method measured in units. Method A is the forecast method with the least MAE. Normally, it is either the 3-month weighted average method or 6-month weighted average method.
  - MethodAR$: savings based on Method A inventory management method measured in dollars;
  - MethodBR#: savings based on Method B inventory management method measured in units. Method B is the forecast method with the second least MAE. Normally, it is either the 3-month weighted average method or 6-month weighted average method.
  - MethodBR$: savings based on Method B inventory management method measured in dollars;
- We can achieve approximately USD 3.8 or 3.9 million reduction in inventory if

proper inventory management practices are carried out using the proposed inventory management model together with the appropriate forecasting methods.

- The results in red represent the case where the actual inventory is out of stock or below the expected level to maintain the desired demand satisfaction.
- In the actual context, InFocus should select the method that provides the smallest MAE or the greatest savings in inventory. Based on the results, we recommend the results obtained by using the improved version of the weighted average method by adjusting the weights to obtain the least MAE.
- We can also observe that, even for the case of using the current forecast method, InFocus can save USD 3.887 million if it follows a disciplined procurement practices rather than procuring service parts in huge quantities in one shot. The large discrepancy between the actual inventory and the prediction using the current method comes from two main sources, wrong output from Servigistics and InFocus failed to adopt the scientific procurement actions.
- We can also observe that the savings obtained using different methods are comparable. Hence, the benefit, or the amount of savings from service parts inventory, will mainly come from better discipline in InFocus' procurement actions. But by improving the forecasting accuracy, greater savings can be achieved which is proven by the result of Method A.

Chapter 8 Conclusions and recommendations

Overview: Based on the problem given, we performed an analysis both qualitatively and quantitatively to understand Servigistics software and to study the service parts planning process. Hence, we present our conclusions in two parts, qualitative and quantitative conclusions.

8.1 Qualitative analysis conclusions

- ✓ Servigistics is a well-designed, scientifically based software tool suitable for service parts planning;
- ✓ Servigistics employs the appropriate forecasting method, 6-month weighted average method;
- ✓ Servigistics uses the valid inventory management model, dynamic continuous review model;
- ✓ Not all the information fed into Servigistics is up-to-date which may seriously affect the validity of the outputs generated by Servigistics. The key problems are summarized below:
  - ✓ The "pipeline history" is not well maintained or up-to-date and some of the pipeline records are seriously wrong which leads to serious problems of undesired inventory levels and low demand satisfactions.
  - ✓ The problem is most serious with standard deviation of procurement lead time. Procurement lead time is calculated by counting the difference in days between the Purchase Order (PO) and Delivery Order (DO). InFocus didn't pay close attention to service parts planning in the past few years and their procurement actions are mostly based on ad-hoc basis rather than strategic planning practices; this has resulted highly variable realized lead times, which the Servigistics tool then uses as its estimate of the procurement lead time. This results in the serious problems of holding unnecessary inventories and having significant amount of back-orders. Hence, InFocus ends up paying huge amount of money for the excess inventory, yet its demand satisfaction is still low because of the significant amount of back-orders.

In summary, InFocus has the right tool, Servigistics planning tool, but it failed to use it carefully and properly in the past. This results in the current situation of holding huge amount of unnecessary inventory yet having low demand satisfaction. But it has the great potential of lowering its reverse logistics management cost by correcting its inventory management practice. The quick calculation indicated that inventory can be reduced by USD 3 million if the right practices are adopted.

8.2 Quantitative analysis conclusions

- ✓ Current forecasting accuracy is around 64% calculated as "MAE/D"; this tells us that current average forecasting error is about two thirds of the expected demand. This value is obtained by taking the grand average of 17 "MAE/Ds" using selected service parts. The current 6-month weighted average method works well for some parts but it fails to do well for some other parts.
- ✓ Forecasting accuracy can be improved by approximately 36% by adjusting the weights used for 6-month weighted average method.
- ✓ Forecasting accuracy can be improved by approximately 38% by reducing the past records used from 6 to 3 using 3-month weighted average method.
- ✓ Linear regression model can offer good forecasting results which are comparable to that obtained using the improved weighted average method; however, we think it is too difficult to implement in practice.
- ✓ Forecasting based on statistical result and failure rates does not offer as good results as weighted average method in general.
- ✓ On the average, the inventory can be reduced by approximately USD 3.8 million dollars if proper inventory management actions were taken. This accounts for almost 15% of the current inventories, and is based on the studies using 17 engines. Hence, even greater savings and improvements might be possible if a thorough analysis can be done across all important and expensive service parts.

The key to lower the reverse logistics management cost is to improve the inventory management process. Procurement of new parts should be based on following the dynamic continuous review inventory model, for which the control parameters (the reorder point and economic order quantity) are properly set. That is, InFocus should use a well established inventory model so as to procure the economic amount when it is needed, rather than buying everything in one shot.

8.3 Recommendations

Some immediate actions should be taken by InFocus in order to improve the current situation. In order to solve the problem completely, some long term development and training plans should also be put into practice.

8.3.1 Immediate actions that InFocus shall take

- ✓ Update service parts lead times, establish and maintain a good database for keeping various lead times;
- ✓ Start managing service parts planning scientifically following the scientific recommended actions from the Servigistics tool, once it has accurate information in the system. This is very critical for InFocus to improve its inventories to the desired levels and maintain it at the desired level and achieve the expected demand satisfaction at the same time.
- ✓ Contact Servigistic Inc. to discuss how to improve the current weights selection. We have shown that it is possible to obtain better forecasting results by adjusting the weights.

8.3.2 Long term development and training plans

It will benefit InFocus if a proper long term training and development plan can be put in place. InFocus shall develop training program for its planners. Planners should be equipped with basic supply chain knowledge so that scientific decisions can be made improving the demand forecasts and for managing service parts inventory. This can not be carried out within a short time frame; hence it is suggested to be designed and put into place for long term benefit.

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